

REVIEW OF PUBLISHED LITERATURE ON INVASIVE SPECIES

WITH A FOCUS ON YUKON TERRITORY

PREPARED FOR THE YUKON INVASIVE SPECIES COUNCIL BY:

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INTRODUCTION

The aim of this annotated bibliography is to provide easy and accessible reference to the current published literature on non-native and invasive species in Yukon Territory. The literature review was guided by the definition of invasive species used by the Yukon Invasive Species Council (YISC):

An invasive species is defined as an organism (plant, animal, fungus, or bacterium) that is introduced and has negative effects on our economy, our environment, or our health. Not all introduced species are invasive. The term “invasive” is reserved for the most aggressive species that reproduce rapidly and cause major changes to the areas where they become established.


Given that the identification of particular species as “invasive” is a somewhat subjective and moving target, this review encompasses a broad sweep of the literature that includes as many non-native species as possible, whether or not they are considered harmful or invasive. Errors of omission were considered to be more costly than errors of inclusion; consequently any references considered likely to be of interest from the peer-reviewed scientific literature were included to the extent possible. However, this list cannot be considered exhaustive and it is always possible that some important material has been missed. Periodic updating of the bibliography is recommended to maintain it as a thorough and accessible record of relevant material. Finally, any views or interpretations presented here in the summaries of each section are those of the report compiler and should not be interpreted as representing viewpoints of the YISC.

METHODS

The following criteria were used to assemble a set of publications from the peer-reviewed scientific literature relevant to Yukon invasive species: a) biogeographical context, b) content related to non-native species, and c) indexing by online databases of scientific literature. The criteria related to biogeographical context set the following priorities for inclusion (in order): 1. Publications directly related to Yukon Territory, 2. Publications reporting research in adjacent Alaska and western Canada, 3. General publications related to invasive species in boreal and arctic habitats. All of the publications included in the literature review were required to have content related to non-native species, including broad taxonomic groups of plants and animals but largely excluding microorganisms except those that pose

disease risk to native plants or animals. A broad literature related to agricultural weed control and mining reclamation was excluded as being outside the scope of this project. Finally, the literature review relied heavily on identification of publications indexed in scientific research databases, primarily ISI Web of Science. Unpublished reports already collected by YISC were also included.

What follows is an annotated bibliography that compiles published scientific literature on non-native and potentially invasive species relevant to Yukon Territory that should be up to date to September 2021. References are organized into broad functional groups (terrestrial plants, terrestrial animals, and aquatic organisms) and subdivided into geographic regions (Yukon, Alaska, other parts of Canada), followed by a short section containing general references likely to be of broader interest. Sections are introduced with a summary of points considered to be of particular interest in relation to Yukon invasive species. Each publication is listed with a full bibliographic citation along with either the published abstract or a short summary compiled for this report. Within a grouping, publications are organized based on first author name and publication year. Author name underlined indicates reference has been downloaded and saved to a shared folder for further reading. Where appropriate, bold font text has been used to highlight names and research locations in the published abstracts of studies reporting on non-native species in Yukon Territory. Where this material has not been included in the original abstract, it has been added here, denoted by text enclosed in brackets [...].



ANNOTATED BIBLIOGRAPHY

1. TERRESTRIAL PLANTS

1A. YUKON STUDIES OF NON-NATIVE PLANTS

Studies of non-native plants in Yukon Territory to date consist largely of botanical and roadside surveys documenting the presence and location of non-native species.

A. Botanical records:

- a. YG specialist Bruce Bennett has a long-term collaboration with plant taxonomist William Cody and other experts that has resulted in 8 published updates to the Flora of Yukon Territory, which include new reports of previously undocumented non-native plants. Publications report plant occurrences arising from botanical records collected across the territory, as well as specific surveys in Kluane National Park (Cody et al. 2004, 2005) and the Peel River watershed (Cody et al. 2003).

B. Invasive plant surveys:

- a. Several unpublished reports describe results of surveys for invasive plants along roadsides and in specific communities or locations. These provide useful baseline references for non-native plants present in Dawson City (Cooley 2009, Parker 2019), Teslin (Hogan and Jules 2015), and Kluane National Park (Davidson 2016).
- b. Roadside surveys conducted for Yukon Government in 2007 (Line et al. 2008) and 2016 (Rosie 2016) provide information on the locations of invasive plants along the Yukon's major road system. Mapping efforts have emphasized the distribution of white sweetclover (*Melilotus albus*) along road corridors, but the distributions of several other invasive plants were recorded and described. These surveys provide a useful tool for ongoing monitoring and planning for invasive species control.
- c. Additional roadside surveys of native and non-native plant communities along the North Klondike Highway between Whitehorse and Dawson City formed the basis of a MSc thesis on plant traits and community assembly (Leathem 2014). The surveys identified seven common non-native plant species: *Taraxacum officinale* (dandelion), *Trifolium hybridum* (alsike clover), *Melilotus albus* (white sweetclover), *Bromus inermis* (smooth

brome), *Crepis tectorum* (narrowleaf hawkbeard), *Medicago sativa* (alfalfa) and *Plantago major* (common plantain). Comparison of plant traits found that non-native species tended to have a higher specific leaf area (usually thinner, more photosynthetically efficient leaves) than native plants in the same communities (Leathem 2014).

C. Natural range expansion:

- a. One study (Johnstone et al. 2003) of tangential interest documents the processes of ongoing range expansion of native lodgepole pine (*Pinus contorta ssp. latifolia*) into central and western Yukon Territory. Lodgepole pine is considered to be a non-native and potentially invasive species in the boreal forests of interior Alaska.

Bennett, B. A., Catling, P. M., Cody, W. J., & Argus, G. W. (2010). New Records of Vascular Plants in the Yukon Territory VIII. CANADIAN FIELD-NATURALIST, 124(1), 1–27.

Published Abstract: Forty-seven taxa, 35 native and 12 introduced, are reported as new to the flora of Yukon and nine taxa previously reported are deleted. The new native taxa are: *Artemisia arctica ssp. comata*, *Botrychium alaskense*, *Botrychium minganense*, *Bromns richardsonii*, *Calamagrostis holmii*, *Carex incurviformis*, *Carex mackenziei*, *Cat-ex microchaeta ssp. nesophila*, *Cares ramenskii*, *Carex rariflora var. androgyna*, *Cares tahoensis*, *Cares xerantica*, *Carex x flavicans*, *Deschampsia sukatschewii*, *Eleocharis erythropoda*, *Eleocharis macrostachya*, *Eleocharis mamillata*, *Erigeron ochroleucus*, *Impatiens noli-tangere*, *Limnorchis huronensis*, *Nymphaea tetragona*, *Polygonum douglasii ssp. douglasii*, *Potamogeton natans*, *Potentilla crebridens ssp. hemicryophila*, *Puccinellia tenella asp. langeana*, *Rumex beringensis*, *Salix farriae*, *Salix glauca ssp. Stipuli fera*, *Saussurea nuda*, *Saxifraga hyperbole*, *Saxifraga rivularis asp. arctolitoralis*, *Silene soczavana var. macrosperma*, *Symphyotrichum subspicatum*, *Taraxacum hyparcticum*, and *Zannichellia palustris*. **The new introduced taxa are: *Acer negundo*, *Avena fatua*, *Camelina microcarpa*, *Crepis capillaris*, *Hippophae rhamnoides*, *Lamium amplexicaule*, *Linaria dalmatica*, *Medicago lupulina*, *Prunus padus*, *Rumex pseudonatronatus*, *Valeriana officinale*, and *Viola tricolor*.** Deleted taxa are: *Aster laevis var. geyeri*, *Carex athrostachya*, *Elatine triantha*, *Camelina saliva*, *Erysimum cheiri*, *Galium palustre*, *Impatiens capensis*, *Platanthera hyperborea*, and *Sonchus oleraceus*. Vouchers are cited and general notes on distribution and identification are provided. Four of the native taxa reported here are new to Canada: *Botrychium alaskense*, *Cares microchaeta ssp. nesophila*, *Potentilla crebridens asp. hemicryophila* and *Rumex beringensis*.

Cody, W. J., Bennett, B. A., & Caswell, P. (2005). New records of vascular plants in the Yukon Territory VII. *CANADIAN FIELD-NATURALIST*, 119(3), 417–436.
<https://doi.org/10.22621/cfn.v119i3.154>

Published Abstract: Based on field reconnaissance mainly in 2003 in Kluane National Park but also many other areas throughout the Yukon, information is provided on geographically significant plant occurrences. Thirteen native taxa, *Agrostis humilis*, *Blysmopsis rufa*, *Carex bebbii*, *C. lenticularis* var. *dolia*, *C. nigricans*, *C. sartwellii*, *C. siccata*, *Diphasiastrum sitchense*, *Najas flexilis*, *Oxytropis arctica* var. *arctica*, *Oxytropis arctica* var. *murrayi*, *Saxitaga nelsoniana* ssp. *carlottae* and *Swertia perennis* and **two introduced taxa, *Bromus japonicas* and *Leymus mollis* ssp. *mollis* s.1.** are reported new to the flora of the Yukon Territory. Significant range extensions for 109 native and eight introduced taxa are included and three species, *Clematis occidentalis*, *Polygonum persicaria*, and *Verbena hastata* are deleted from the flora.

Cody, W., Kennedy, C., Bennett, B., & Caswell, P. (2004). New records of vascular plants in the Yukon territory VI. *CANADIAN FIELD-NATURALIST*, 118(4), 558–578.
<https://doi.org/10.22621/cfn.v118i4.58>

Published Abstract: Based on field reconnaissance mainly in 2002 in the southern part of the Yukon and particularly in and adjacent to Kluane National Park, information is provided on geographically significant plant occurrences. Six native taxa: *Atriplex alaskensis*, *Claytonia megarrhiza*, *Corispermum ochotense* var. *alaskanum*, *Oxytropis arctica*, *Polemonium acutiflorum* forma *lacteum* and *Polemonium boreale* forma *albiflorum*. and **four introduced taxa: *Arabis caucasica*, *Camelina sativa*, *Senecio eremophilus*, and *Setaria viridis*** are reported new to the known flora of the Yukon Territory. Significant range extensions for 158 native and 21 introduced taxa are included. *Parrya arctica*, *Armoracia rusticana*, *Atriplex panda* and *Papaver nudicaule* ssp. *nudicaule* are excluded from the Yukon flora.

Cody, W., Kennedy, C., Bennett, B., & Staniforth, J. (2003). New records of vascular plants in the Yukon territory V. *CANADIAN FIELD-NATURALIST*, 117(2), 278–301.
<https://doi.org/10.22621/cfn.v117i2.707>

Published Abstract: Based on field reconnaissance in 2000 and 2001 throughout Yukon but particularly in the areas of the Upper Bonnet Plume River, Wind River, Eagle Plains and Vuntut

National Park, information is provided on geographically significant plant occurrences. Three native taxa, *Draba kananaskis*, *Hieracium albiflorum* and *Prunella vulgaris ssp. lanceolata* and **five introduced taxa, *Alopecurus geniculatus*, *Dactylis glomerata*, *Elymus junceus*, *Lotus corniculatus*, and *Verbena hastata*** are reported new to the known flora of the Yukon Territory. Significant range extensions for 190 native and 24 introduced taxa are included. *Maianthemum dilatatum* is excluded from the Yukon flora.

Cody, W., Kennedy, C., Bennett, B., & Loewen, V. (2002). New records of vascular plants in the Yukon Territory IV. *CANADIAN FIELD-NATURALIST*, 116(3), 446–474.

Published Abstract: Two native taxa, *Crassula aquatica* and *Erysimum inconspicuum*, and **two introduced taxa, *Elymus elongatus ssp. ponticus* and *Erysimum cheiri***, are reported new to the known flora of the Yukon Territory. Significant range extensions for 199 native and 27 introduced taxa and comments on one native taxon, *Ranunculus cooleyae*, previously reported in the Territory but omitted in the Mora, are also included.

Cody, W., Kennedy, C., & Bennett, B. (2001). New records of vascular plants in the Yukon territory III. *CANADIAN FIELD-NATURALIST*, 115(2), 301–322.

Published Abstract: Ten native taxa including *Arabis boivinii*, *Carex aquatilis ssp. stans*, *Descurainia incisa var. incisa*, *Draba lonchocarpa var. vestita*, *Isoetes maritima*, *Lepidium densiflorum var. macrocarpum*, *Malaxis paludosa*, *Phyllodoce X intermedia*, *Scirpus acutus*, *Stipa hymenoides* and *Taraxacum carneocoloratum* are reported new to the known flora of the Yukon Territory. **Three introduced taxa including *Centaurea cyanus*, *Lolium perenne ssp. multiflorum*, *Rheum rhaponticum* and *Sorbaria sorbifolia*** are also reported as new to the known flora. Significant range extensions within the Territory are reported for 127 native and 21 introduced taxa and comments are presented on four native taxa. Of these, 10 native and three introduced are new for the Territory. The total vascular flora is now 1163 species.

Cody, W., Kennedy, C., & Bennett, B. (2000). New records of vascular plants in the Yukon Territory II. *CANADIAN FIELD-NATURALIST*, 114(3), 417–443.

Published Abstract: Nine native taxa including *Carex oligosperma*, *C. pauciflora*, *C. pellita*,

Chimaphila umbellata ssp. *occidentalis*, *Draba densifolia*, *xElyleymus hirtiflorus*, *Eriophorum vaginatum* ssp. *spissum*, *Impatiens capensis*, and *Rhus radicans* are reported new to the known flora of the Yukon Territory. **Eight introduced taxa** [*Asperago procumbens*, *Caragana arborescens*, *Cerastium nutans*, *Elymus sibiricus*, *Fagopyrum esculentum*, *Leymus angustus*, *Sonchus oleraceus*, *Trifolium cyanthiferum*] are also reported as new to the known flora. Significant range extensions within the Territory are reported for 180 native and 17 introduced taxa. Comments are presented on three native taxa and two native taxa are deleted from the Territory.

Cody, W., Kennedy, C., & Bennett, B. (1998). New records of vascular plants in the Yukon Territory. *CANADIAN FIELD-NATURALIST*, 112(2), 289–328.

Published Abstract: Thirteen native taxa including *Alisma plantago-aquatica* var. *americana*, *Carex aquatilis* ssp. *stans*, *C. lenticularis* var. *lipocarpa*, *Cassiope mertensiana*, *Dryopteris carthusiana*, *Lathyrus ochroleucus*, *Lonicera dioica* var. *glaucescens*, *Maianthemum canadense* ssp. *interius*, *Papaver alboroseum*, *Platanthera orbiculata*, *Potamogeton strictifolius*, *Salix raupii* and *Vaccinium membranaceum* are reported new to the known flora of the Yukon Territory. **Nine introduced taxa** [*Astragalus cicer*, *Centaurea maculosa*, *Cirsium arvense*, *Elymus hispidus*, *Lolium perenne* ssp. *perenne*, *Rorippa curvipes* var. *truncata*, *Silene noctiflora*, *Tanacetum vulgare*, *Tragopon dubius*] are also reported as new to the known flora. Significant range extensions within the Territory are reported for 287 native and 17 introduced taxa. Most of the range extensions involve the eastern portion of the Territory. Comments are presented on 11 native taxa and two native taxa are deleted from the Territory.

Cooley, D. (2009). Mapping invasive plants in downtown Dawson City, 2008. Yukon Fish and Wildlife Branch Report SR-09-01, Whitehorse, Yukon. 18 pp.

Summary: This Yukon Government report describes the results of a baseline occupancy survey that focused on six of the most aggressive invasive plants found around **Dawson City, Yukon**. Surveys were conducted in late July 2008 and examined the downtown core of Dawson City. At the time of the survey, slightly less than half (41%) of the available area was colonized by at least one invasive plant species. **Tufted vetch** (*Vicia cracca*) and **white sweetclover** (*Melilotus alba*) were particularly abundant. In addition, **yellow sweetclover** (*Melilotus officinalis*), **butter and eggs** (*Linaria vulgaris*), **common catchfly** (*Silene vulgaris*), **ox-eye daisy** (*Leucanthemum vulgare*) were present at lower abundance.

Davidson, S. (2016). Invasive species in Kluane National Park and Reserve: 2016 management Unpublished report. Parks Canada, Haines Junction, Yukon. 6 pp.

Summary: This unpublished report describes pulling and mapping activities related to invasive plants carried out at **Kluane National Park** in 2016. Known locations of **lucerne (*Medicago falcata*)**, **sweetclover (*Melilotus alba*)**, **butter and eggs (*Linaria vulgaris*)**, and **creeping thistle (*Cirsium arvense*)** were targeted for hand pulling of plants. New areas (Tachal Dhal road, horse trail and site near Bighorn Lake) were investigated for invasive plants but none were found.

Hogan, N. & Jules, C. (2015). Results of surveying Teslin's invasive plant community. Unpublished report. Teslin Tlingit Council Lands and Resources, Teslin, Yukon. 23 pp.

Summary: This report describes the results of roadside surveys for non-native plant species conducted in **Teslin** during summer 2015. The most common non-native species found was ***Taraxicum officinale* (dandelion)**, although surveys also confirmed presence of ***Trifolium hybridum* (alsike clover)**, ***Melilotus albus* (white sweetclover)**, ***Bromus inermis* (smooth brome)**, and ***Crepis tectorum* (narrowleaf hawkbeard)**. The report concludes by offering suggestions for a managing and mitigating impacts of invasive plants based on early detection and ongoing monitoring.

Johnstone, J.F. & Chapin, F.S. III (2003). Non-equilibrium succession dynamics indicate continued northern migration of lodgepole pine. *GLOBAL CHANGE BIOLOGY*, 9(10), 1401–1409. <https://doi.org/10.1046/j.1365-2486.2003.00661.x>

Published Abstract: Because species affect ecosystem functioning, understanding migration processes is a key component of predicting future ecosystem responses to climate change. This study provides evidence of range expansion under current climatic conditions of an indigenous species with strong ecosystem effects. Surveys of stands along the northern distribution limit of **lodgepole pine (*Pinus contorta var. latifolia*) in central Yukon Territory, Canada** showed consistent increases in pine dominance following fire. These patterns differed strongly from those observed at sites where pine has been present for several thousand years. Differences in species thinning rates are unlikely to account for the observed increases in pine dominance. Rates of pine regeneration at its range limits were equivalent to those of spruce, indicating a capacity for rapid local population expansion. The study also found no evidence of strong climatic limitation of pine population growth at the northern distribution limit. We interpret these data as evidence of current pine expansion at its range limits and conclude that the northern distribution of lodgepole pine is not in equilibrium with current climate. This study has implications for our ability to predict

vegetation response to climate change when populations may lag in their response to climate.

Leathem, J. A. (2014). Community assembly along sub-arctic roadsides: the role of plant functional traits in native and exotic species. M.Sc. thesis, Department of Botany, University of British Columbia, Vancouver, BC. 107 pp.

Published Abstract: Much is known about plant-environment associations, but we are far from able to predict community species composition under a given set of environmental conditions. Recent research using functional traits suggests niche-based processes are vital in structuring communities, though the generality of results across different ecosystems is unknown. I investigated community trait distribution along environmental gradients in sub-Arctic roadsides--communities which represent novel ecosystems in which to apply trait-based analysis, and which allow for the comparison of ecological strategies and trait distribution of native and exotic species. While these environments have features specific to northern latitudes, they also broadly represent global roadside environments and their important role in the establishment and spread of exotic species. Invasive exotic species present a pervasive threat to global diversity, and understanding mechanisms of assembly, coexistence and strategies of native and exotic roadside communities can improve our ability to predict invasive species behaviour. I measured species abundance and three functional traits in **42 roadside plots in the Yukon Territory** and compared community traits across elevation, latitude and age of road. Across all species, abundance-weighted community height was negatively correlated with elevation and positively correlated to latitude. Native and exotic species tracked environment differently, however, and exotic species showed correlations between height and road age as well as between specific leaf area (SLA) and latitude that were not present among native species. A comparison of mean trait values of native and exotic species irrespective of environment revealed specific leaf area (SLA) was greater in exotic species than native species. In addition, I used three null models to test for habitat filtering and competitive exclusion, two important niche-based assembly processes. Ranges of trait values across plots were smaller than expected and trait values more evenly spaced compared to random samples from the regional species pool, suggesting both habitat filtering and competitive exclusion (limiting similarity) shape these disturbance communities. Both processes were found to also affect both presence/absence and abundance of species. Understanding mechanisms of community assembly along roadsides and the characterisation of native and exotic community constituents will have important implications for development of conservation management strategies.

Line, J., Brunner, G., Rosie, R. & Russell, K. (2008). Results of the 2007 invasive plants roadside inventory in Yukon. Unpublished report. Fish and Wildlife Branch, NatureServe Yukon,

Whitehorse, Yukon. 38 pp.

Summary: Over the last decade non-native plants have been observed expanding their ranges in Yukon and a number of new non-native plants have been discovered. There is concern that with climate change invasive plants could cause ecological and economic damage like that seen in southern jurisdictions and in Alaska. In order to develop a strategy for combating invasive plants, we required a baseline inventory. Along **major Yukon highways**, we mapped the distribution of **Sweetclover (*Melilotus albus*)**, a plant that threatens native habitats along rivers. The patterns of distribution of Sweetclover show that invasion is most pronounced in areas that have received recent highway construction and maintenance. Furthermore, populations around bridges and culverts pose a risk to river ecosystems. We also recorded the presence and abundance of 28 non-native and invasive species at rest stops, campgrounds, gravel pits and other disturbed areas along major Yukon highways. Pullouts and rest stops which receive the most vehicle traffic had the highest diversity of non-native plants. This work provided baseline data for monitoring the spread of invasive plants along highways and offers suggestions for a long-term monitoring methodology. Location information for invasive plants presented in this report can be used in an Early Detection and Rapid Response strategy.

Parker, S. (2019). Dawson City invasive plant survey 2019. Unpublished report. Fish and Wildlife Branch, Environment Yukon, Whitehorse, Yukon. 14 pp.

Summary: This report describes results of an invasive plant survey intended to update and refine results of an earlier survey in the **Dawson City** area in 2008 (Cooley 2009). The survey documented **8 species of invasive plants** and their distribution in the streets of Dawson City, along Mary McLeod Road, and adjacent to the Yukon River within the town. Results indicated the presence and relative density of the surveyed invasive species were relatively similar to what they were in 2008.

Rosie, R. (2017). 2018 invasive plant roadside survey, Yukon Territory. Unpublished report. Yukon Government Invasive Species Interdepartmental Working Group, Whitehorse, Yukon. 101 pp.

Summary: The 2016 roadside survey provides insight into changes in distribution and abundance of **White Sweetclover (*Melilotus albus*) along Yukon's major highways**, gravel pits, rest areas, pullouts, and watercourses since the 2007 roadside survey, as well as baseline abundance and distribution data for other priority invasive plant species. The 2016 roadside survey surveyed for **14 priority invasive plant species** along Yukon's major highways, gravel pits, rest areas, pullouts, and watercourses. White Sweet-clover was the most common priority invasive plant

species observed along Yukon's major highways, followed by Alsike Clover, Smooth Brome, Narrow-leaf Hawk's-beard, Red Clover, Alfalfa, Yellow Sweet-clover, and Yellow Lucerne. Species found infrequently along major highways included Umbellate Hawkweed, Oxeye Daisy, Reed Canary Grass, Field Sow-thistle, and Common Tansy. Scentless Chamomile was not seen along any of the surveyed roadsides, but a few scattered individuals were noted in a pullout/disturbed area near Sidney Lake on the South Canal Road and in the dump near Johnson's Crossing. Within gravel pits, rest areas, and pull outs the most common and abundant priority invasive species included Narrow-leaf Hawk's-beard, White Sweet-clover, Alsike Clover, and Smooth Brome. Relatively few watercourses had invasive species present; however, 97 watercourses (44%) had priority invasive species present in close vicinity to the watercourse (e.g., around bridges, above banks, or along the road above the watercourse).

1B. ALASKA STUDIES OF NON-NATIVE PLANTS

There have been more detailed investigations of invasive plants in Alaska than in Yukon; studies carried out in the boreal forests of interior Alaska are likely to be particularly relevant to the Yukon context. The studies listed below provide several noteworthy observations:

- A. Vectors and management of non-native plant spread:
 - a. Imports of container-grown ornamental plants represent a source of propagules for non-native plants. A study testing soil from container plants for non-native plant seeds found viable propagules for several invasive species (Conn et al. 2008b). Containers with mineral soil and perennial plants were particularly likely to be contaminated with non-native seed.
 - b. Both locally produced and imported hay or straw contain seeds of non-native plants that can represent an important vector for invasive plant spread (Conn et al. 2010). Use of only locally produced hay does not provide protection against invasive plant spread as there are many invasive species present in local pastures.
 - c. Purchased grass and crop seed also contains many weed seeds that can lead to undesired introductions of non-native plants. A study of seed composition for both Alaska-grown and imported seed lots found a large potential for weed seed contamination, despite regulations designed to limit weeds present in purchased seed (Conn et al. 2012).

- d. On the Kenai Peninsula, multi-use trails had the highest abundance of invasive plants close to the trailhead, highlighting that dispersal distance and amount of traffic are likely to create local hotspots for non-native plant invasion (Bella 2011). This study found the type of trail use (hiking, hiking+biking, hiking+biking+horses, multi-use including motorized transport) did not seem to influence invasive plant distributions.
- e. Non-native plant seeds may also be transported in the gut of wildlife species that feed on them. A study using captive moose found that seeds of white sweetclover (*Melilotus alba*) could be passed through the gut and successfully germinate from feces as much as 11 days after ingestion (Seefeldt et al. 2010). In contrast, seeds of hawkbeard rarely survived passage through the gut. Moose thus have the potential to move seed of some invasive plants through the landscape.

B. Potential impacts of climate change on non-native plant spread:

- a. Habitat suitability modelling was used to explore the potential impacts of climate change on habitat suitability for 3 invasive species in SE Alaska, including sweetclover (*Melilotus alba*) (Jarnevich et al. 2014). Local site conditions and disturbance were important in determining habitat suitability, and the models did not forecast large range expansions with climate warming. Results of a preliminary model for sweetclover in interior Alaska were included in supplementary materials for the paper and indicate that most of interior Alaska (N to the foothills of the Brooks Range) already provides suitable habitat for white sweetclover.
- b. The responses of native and non-native species to variations in growing season length were examined for multiple species near Fairbanks in interior Alaska (Mulder et al. 2019). Non-native species did not start flowering earlier with a warm spring as native species did, but they were more successful at growing later and delaying senescence during warm fall conditions. This suggests that extending the growing season later into fall may favor increased growth of non-native plants.

C. Soil properties that affect non-native plant distributions:

- a. Habitat preferences of sweetclover for alkaline soils and gravel create a pathway for white sweetclover (*Melilotus alba*) to spread from areas where it grows abundantly on roadside gravels into downstream river systems in locations where roads intersect with river floodplains (Conn et al. 2008a).
- b. In Denali National Park, disturbed areas near the park entrance were more likely to host high abundances of dandelion (*Taraxacum officinale*) where soils had been fertilized and

had high amounts of potassium, and where southerly exposure resulted in warmer soils (Densmore 2008).

- c. Dandelion was also the most likely non-native plant to be invading burned forest stands from the roadside in interior Alaska. Soils where most of the organic layer was burned away supported higher germination rates in a seeding experiment with non-native plants (Walker et al. 2017).
 - d. Local variations in soils and moisture availability appear to be more important than fire disturbance alone in determining the potential for non-native plants to invade after a burn. Rapid colonization by mosses may help burned soils resist colonization by invasive plants (Spellman et al. 2014).
- D. Impacts of non-native plants (specifically, white sweetclover (*Melilotus alba*, syn. *M. albus*)) on native species:
- a. Spread of sweetclover into river floodplains was found to create shaded habitats that decreased the survival and abundance of native plants that would normally colonize early successional habitats (Spellman et al. 2011).
 - b. Patches of abundant sweetclover appeared to attract native pollinators to an area and actually enhanced fruit set of the native cranberry (*Vaccinium vitis-idaea*), while having more neutral effects on native Labrador tea (*Rhododendron groenlandicum*). There was some evidence for competition for pollinators between sweetclover and Labrador tea (Spellman et al. 2015).
 - c. The effects of a sweetclover patch on native species pollination was dependent on distance away and the size of the sweetclover patch, and varied based on the pollination ecology of the species. Positive effects of sweetclover patches on native species pollination and fruit set were more apparent than negative effects (Spellman et al. 2016).

Bella, E. M. (2011). Invasion prediction on Alaska trails: Distribution, habitat, and trail use. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 4(3), 296–305. <https://doi.org/10.1614/IPSM-D-10-00083.1>

Published Abstract: Little is known about the relationship between frequency of occurrence and

the expected maximum distance a nonnative species might spread along a trail once introduced to an ecological system with high native species integrity. Understanding how colonization and invasive plant habitat degradation occur in largely intact ecosystems is challenging. Determining which nonnative species are most likely to spread might be possible, given a suite of environmental or trail conditions. Spread may be linked to a particular set of environmental conditions, or to type and level of trail use. A field study conducted on trails in Forest Service and State Park lands on the Kenai Peninsula, Alaska, was designed to determine frequency and spread distance of all nonnative vascular plant species per 100-m segments keyed to vegetation type, canopy cover class, aspect, trail use level, and trail use type. Although the maximum total number of nonnative species decreased with increased distances from trailheads, the average number of species remained nearly constant. Common dandelion, broadleaf plantain, and annual bluegrass exhibited consistent presence per canopy cover class or vegetation type. A nested subset analysis revealed a significant reduction in nonnative species presence beyond a 500-m distance from a trailhead and a moderately strong nestedness pattern. High-use trails exhibited the greatest numbers of nonnative species at the farthest distances from the trailhead and contained a greater number of less common nonnative species. Alaska and other northern biomes have relatively few widespread invasive problems, offering an opportunity to limit ecosystem degradation by invasion. Results suggest that control strategies might focus on high-use trails with open-canopy habitats to prevent spread.

Conn, J. S., Beattie, K. L., Shephard, M. A., Carlson, M. L., Lapina, I., Hebert, M., Gronquist, R., Densmore, R., & Rasy, M. (2008a). Alaska *Melilotus* invasions: Distribution, origin, and susceptibility of plant communities. *ARCTIC ANTARCTIC AND ALPINE RESEARCH*, 40(2), 298–308. DOI: [https://doi.org/10.1657/1523-0430\(06-007\)\[CONN\]2.0.CO;2](https://doi.org/10.1657/1523-0430(06-007)[CONN]2.0.CO;2)

Published Abstract: *Melilotus alba* and *M. officinalis* were introduced to Alaska in 1913 as potential forage crops. These species have become naturalized and are now invading large, exotic plant-free regions of Alaska. We determined distributions of *M. alba* and *M. officinalis* in Alaska from surveys conducted each summer from 2002 to 2005. *Melilotus alba* and *M. officinalis* occurred at 721 and 205 sites, respectively (39,756 total sites surveyed). The northward limit for *M. alba* and *M. officinalis* was 67.15 degrees N and 64.87 degrees N, respectively. Both species were strictly associated with soil disturbance. *Melilotus alba* extended no farther than 15 m from road edges except where *M. alba* on roadsides met river floodplains and dispersed downriver (Matanuska and Nenana Rivers). *Melilotus* has now reached the Tanana River, a tributary of the Yukon River. Populations on floodplains were most extensive on braided sections. On the Nenana River, soil characteristics did not differ between where *M. alba* was growing versus similar areas where it had not yet reached. The pH of river soils (7.9-8.3) was higher than highway soils (7.3). Upland taiga plant communities grow on acid soils which may protect them from invasion by *Melilotus*, which prefer alkaline soils; however, early succession communities on river floodplains are susceptible because soils are alkaline.

Conn, Jeffery S., Stockdale, C. A., & Morgan, J. C. (2008b). Characterizing pathways of invasive plant spread to Alaska: I. Propagules from container-grown ornamentals. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 1(4), 331–336. DOI: <https://doi.org/10.1614/IPSM-08-063.1>

Published Abstract: To determine the extent and nature of container-grown plant soil as a pathway for introduction of exotic plant species to Alaska, soil from container-grown ornamentals was obtained from vendors and was incubated in the greenhouse. Fifty-four plant species were identified growing in containers or germinating from the soil, and included Canada thistle—a prohibited weed in Alaska—and nine other species listed as invasive in Alaska. The number of species and estimated seed bank were very low for soil from vegetable starts/herbs and herbaceous bedding plants (<2 seedlings/L soil), but was greater for soil from containers containing woody plants, especially balled and burlapped ornamentals (20 seedlings/L soil). Container alien plant seed bank size was strongly related to type of soil. Potting (soil-less) soil contained 1.2 germinating seeds/L, soil-based soil 5.5 seeds/L, and mineral soil 18.7 seeds/L. Growers and vendors were variables that also influenced the size of the container seed bank, suggesting that weed management practiced during production and at the point of sale can greatly influence seed banks of ornamental containers.

Conn, Jeffery S., Stockdale, C. A., Werdin-Pfisterer, N. R., & Morgan, J. C. (2010). Characterizing pathways of invasive plant spread to Alaska: II. Propagules from imported hay and straw. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 3(3), 276–285. <https://doi.org/10.1614/IPSM-D-09-00041.1>

Published Abstract: The extent and nature of spread of exotic plant species to and within Alaska by shipment of hay and straw was studied. The amounts of hay and straw imported into Alaska and the amounts and types of seed in imported and locally produced hay and straw was determined. We purchased alfalfa hay, wheat straw, ryegrass straw, and timothy hay produced in Washington and Oregon (WA-OR) and locally produced straw and hay. The hay and straw were shaken over screens, and the remaining fines were mixed with sterile potting soil and incubated in the greenhouse. Forty-nine plant species were identified from hay and straw, nine of which are ranked as invasive in Alaska, including downy brome, foxtail barley, hare barley, narrowleaf hawksbeard, and quackgrass—a prohibited weed in Alaska. The number of seeds ranged from 0 to 6,205 seeds kg⁻¹, with an average of 585 seeds kg⁻¹, and the number of species ranged from 0 to 12, with an average of 4.2 species per bale. Crop seed comprised a large proportion of the germinated seeds in ryegrass straw, wheat straw, and timothy/brome hay (98, 78, and 62%, respectively), but was less prevalent (ranging from 0 to 38%) in the other three hay and straw crop types. Hay and straw from Alaska contained more total seeds and species than hay and straw from WA-OR, but the difference was not significant when only weed seed was used in the analysis. Alaska-grown timothy/brome hay contained significantly more total seed than alfalfa hay and wheat straw from WA-OR and Alaska-grown barley straw. The grower or distributor of the hay and straw also influenced the number of seeds and species among some crop types. Results of this study document that large numbers of alien plant species are transported by

movements of hay and straw into and within Alaska.

Conn, Jeffery S. (2012). Pathways of invasive plant spread to Alaska: III. Contaminants in crop and grass seed. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 5(2), 270–281.
<https://doi.org/10.1614/IPSM-D-11-00073.1>

Published Abstract: Invasive plants disperse to new areas via numerous pathways. Study of these pathways helps to focus limited budgets toward prevention and early detection. This study examined potentially invasive seed contaminants in imported crops and grass seed as pathways for plant dispersal to Alaska. Crop and grass seed were purchased from 13 Alaska retail outlets representing 14 seed suppliers. Seed bags were sampled using federally mandated protocols and were analyzed for crop seeds that were not supposed to be included and for weed contaminants. Ninety-five weed and 36 contaminant crop taxa were found. Crop seed contained 43 weed taxa and 15 other crop species contaminants, a mean of 6.4 taxa and 3,844 contaminant seed kg⁻¹. Grass seed samples contained 73 weed taxa and 21 crop contaminants, a mean of 3.5 contaminant species and 1,250 seeds kg⁻¹. Two species prohibited by the Alaska seed law were found: Canada thistle was found in a single crop sample, and quackgrass was found in two grass samples. There were no significant relationships between either seed type or supplier and either the number of contaminant species or number of seeds. Labels of 33% of crop samples and 8% of grass samples claimed 0.00% weed seeds, but low (0.007% by weight, 2 species) to high (1.18% by weight, 13 species) amounts of weed contaminants were found. Importation of crop seed is a large pathway for seed movement, causing significant propagule pressure and an increased likelihood of establishment by new invasive plant populations. Prevention of spread via this pathway would be enhanced by changes to seed laws, by greater regulatory enforcement, and by including on the label, the names of all weed and contaminant crop species found in the law-required samples. Consumers could then make decisions on whether to purchase seed based on the potentially invasive species that would be planted with the desired seed.

Densmore, R. V. (2008). Evidence for higher soil temperature and potassium promoting invasion of the common dandelion, *Taraxacum officinale*, in Denali National Park and Preserve, Alaska. *The Canadian Field-Naturalist*, 122(1), 67. DOI: <https://doi.org/10.22621/cfn.v122i1.547>

Published Abstract: Common Dandelion, *Taraxacum officinale ssp. officinale* (dandelion) is expanding its range in Alaska and is of particular concern in National Park Service units. This study investigated the influence of estimated soil temperature, available potassium (K), available phosphorous (P), and total nitrogen (N) on dandelion cover and density on a site near the elevational limit of dandelion. The study site in Denali National Park had been disturbed by construction and was revegetated with native plants 12 years before the study. Seed input to the

study site was abundant. In a multiple regression analysis, higher levels of estimated soil temperature and available K accounted for 79% and 73% of the variation in dandelion cover and density, respectively. Practical control methods include not fertilizing disturbed areas with K, and countering continued expansion of dandelion by monitoring human use areas and undisturbed habitats where soil temperatures are likely to be relatively warm.

Jarnevich, C. S., Holcombe, T. R., Bella, E. M., Carlson, M. L., Graziano, G., Lamb, M., Seefeldt, S. S., & Morissette, J. (2014). Cross-scale assessment of potential habitat shifts in a rapidly changing climate. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 7(3), 491–502.
<https://doi.org/10.1614/IPSM-D-13-00071.1>

Published Abstract: We assessed the ability of climatic, environmental, and anthropogenic variables to predict areas of high-risk for plant invasion and consider the relative importance and contribution of these predictor variables by considering two spatial scales in a region of rapidly changing climate. We created predictive distribution models, using Maxent, for three highly invasive plant species (Canada thistle, white sweetclover, and reed canarygrass) in Alaska at both a regional scale and a local scale. Regional scale models encompassed southern coastal Alaska and were developed from topographic and climatic data at a 2 km (1.2 mi) spatial resolution. Models were applied to future climate (2030). Local scale models were spatially nested within the regional area; these models incorporated physiographic and anthropogenic variables at a 30 m (98.4 ft) resolution. Regional and local models performed well (AUC values > 0.7), with the exception of one species at each spatial scale. Regional models predict an increase in area of suitable habitat for all species by 2030 with a general shift to higher elevation areas; however, the distribution of each species was driven by different climate and topographical variables. In contrast local models indicate that distance to right-of-ways and elevation are associated with habitat suitability for all three species at this spatial level. Combining results from regional models, capturing long-term distribution, and local models, capturing near-term establishment and distribution, offers a new and effective tool for highlighting at-risk areas and provides insight on how variables acting at different scales contribute to suitability predictions. The combinations also provides easy comparison, highlighting agreement between the two scales, where long-term distribution factors predict suitability while near-term do not and vice versa.

Mulder, C. P. H., & Spellman, K., V. (2019). Do longer growing seasons give introduced plants an advantage over native plants in Interior Alaska? *BOTANY*, 97(6), 347–362.
<https://doi.org/10.1139/cjb-2018-0209>

Published Abstract: In interior Alaska, increases in growing season length and rapid expansion of introduced species are altering the environment for native plants. We evaluated whether earlier

springs, warmer summers, and extended autumns alter the phenology of leaves and flowers in native and introduced forbs and shrubs in the boreal understory and open-canopy habitats, and whether the responses provide an advantage to either group. We tracked the phenology of 29 native and 12 introduced species over three years with very different spring, summer, and autumn conditions. The native species produced flowers (but not leaves) earlier than the introduced species, and both groups advanced leaf-out and flowering in the early-snowmelt year. However, shifts in phenology between early and late years were similar for both groups. There was no increase in fruit development rate for either group in the warm summer. In contrast, in the year with the extended autumn, the introduced plants extended leaf production and time of senescence much more than native species. While growth form and leaf habit could explain the differences in phenology between native and introduced groups in spring and summer, these traits could not account for differences in autumn. We conclude that in boreal Alaska extended autumns may benefit introduced species more than native ones.

Seefeldt, S. S., Collins, W. B., Kuhl, J. C., & Clauss, M. (2010). White sweetclover (*Melilotus albus*) and narrowleaf hawksbeard (*Crepis tectorum*) seed germination after passing through moose. INVASIVE PLANT SCIENCE AND MANAGEMENT, 3(1), 26–31. <https://doi.org/10.1614/IPSM-09-034.1>

Published Abstract: White sweetclover and narrowleaf hawksbeard are nonindigenous invasive plant species in Alaska that are rapidly spreading, including into areas that are otherwise free of nonindigenous plants. There has been concern that native moose could be dispersing germinable seed from these plants after ingestion. To address this concern, a study was conducted involving tame moose at the University of Alaska Fairbanks Agriculture and Forestry Experiment Station, Matanuska Experiment Farm, Palmer, AK. Objectives were to determine if seeds from these two plant species could survive mastication and digestive passage through moose, whether this passage impacted seed germination, and whether seed passage rates were the same as similar sized Cr-mordanted Fiber. In this study, narrowleaf hawksbeard seed rarely survived mastication and digestion with only five seedlings recovered from 42,000 germinable seed fed to the moose. About 16% of germinable white sweetclover seed (3,595 of 22,000) fed to the moose produced seedlings. Most of the sweetclover seedlings came from feces produced 2 and 3 d after feeding. In two moose, sweetclover seedlings were grown from fecal material that was passed 11 d after feeding, raising the possibility that seeds could be transported long distances after ingestion. Cr-mordanted Fiber passage did not closely follow seedling producing seed, possibly because time in the rumen might reduce seed germination. Once roadsides in Alaska become infested with white sweetclover, moose can then serve as a transport vector of these weeds into river channels and floodplains, which are distant from roads. This information will impact white sweetclover management programs and alert land managers to the potential for other instances of wildlife-mediated seed dispersal.

Spellman, B. T., & Wurtz, T. L. (2011). Invasive sweetclover (*Melilotus alba*) impacts native seedling recruitment along floodplains of interior Alaska. *BIOLOGICAL INVASIONS*, 13(8), 1779–1790. <https://doi.org/10.1007/s10530-010-9931-4>

Published Abstract: Sweetclover (*Melilotus alba*) is a non-native legume that has formed dense and extensive patches along several rivers in Alaska. Our research objective was to determine if sweetclover impacts recruitment of native seedlings in floodplain habitats. To determine if sweetclover impacted recruitment, we conducted a removal experiment along two rivers in interior Alaska. When compared to areas where sweetclover was removed, areas with sweetclover had approximately 50% greater mortality of native seedlings, 25% less recruiting species, and a significant reduction in the quantity of light available to seedlings on floodplain surfaces. To determine if sweetclover shading was a mechanism that limited seedling recruitment, we grew eight common early-successional floodplain plant species in a greenhouse under a range of lighting conditions that were representative of shading under sweetclover. We observed that species restricted to the earliest seral stages of floodplain succession experienced greater reductions in biomass than species that persist into later stages of floodplain succession. Shading seedlings in a greenhouse did not lead to mortality during the growing season. However, when seedlings were over-wintered, we observed that greater shading during the growing season can result in higher seedling mortality. Our study indicates sweetclover invasions have created a novel shade environment in early seral floodplain plant communities, which has the potential to alter community composition. To preserve biodiversity and structure of plant communities, sweetclover should be actively managed to prevent its spread onto additional glacial rivers in Alaska.

Spellman, K. V., Mulder, C. P. H., & Hollingsworth, T. N. (2014). Susceptibility of burned black spruce (*Picea mariana*) forests to non-native plant invasions in interior Alaska. *BIOLOGICAL INVASIONS*, 16(9), 1879–1895. <https://doi.org/10.1007/s10530-013-0633-6>

Published Abstract: As climate rapidly warms at high-latitudes, the boreal forest faces the simultaneous threats of increasing invasive plant abundances and increasing area burned by wildfire. Highly flammable and widespread black spruce (*Picea mariana*) forest represents a boreal habitat that may be increasingly susceptible to non-native plant invasion. This study assess the role of burn severity, site moisture and time elapsed since burning in determining the invisibility of black spruce forests. We conducted field surveys for presence of non-native plants at 99 burned black spruce forest sites burned in 2004 in three regions of interior Alaska that spanned a gradient of burn severities and site moisture levels, and a chronosequence of sites in a single region that had burned in 1987, 1994, and 1999. We also conducted a greenhouse

experiment where we grew invasive plants in vegetation and soil cores taken from a subset of these sites. In both our field survey and the greenhouse experiment, regional differences in soils and vegetation between burn complexes outweighed local burn severity or site moisture in determining the invasibility of burned black spruce sites. In the greenhouse experiments using cores from the 2004 burns, we found that the invasive focal species grew better in cores with soil and vegetation properties characteristic of low severity burns. Invasive plant growth in the greenhouse was greater in cores from the chronosequence burns with higher soil water holding capacity or lower native vascular biomass. We concluded that there are differences in susceptibility to non-native plant invasions between different regions of boreal Alaska based on native species regeneration. Re-establishment of native ground cover vegetation, including rapidly colonizing bryophytes, appear to offer burned areas a level of resistance to invasive plant establishment.

Spellman, K. V., Schneller, L. C., Mulder, C. P. H., & Carlson, M. L. (2015). Effects of non-native *Melilotus albus* on pollination and reproduction in two boreal shrubs. *OECOLOGIA*, 179(2), 495–507. <https://doi.org/10.1007/s00442-015-3364-9>

Published Abstract: The establishment of abundantly flowered, highly rewarding non-native plant species is expected to have strong consequences for native plants through altered pollination services, particularly in boreal forest where the flowering season is short and the pollinator pool is small. In 18 boreal forest sites, we added flowering *Melilotus albus* to some sites and left some sites as controls in 2 different years to test if the invasive plant influences the pollination and reproductive success of two co-flowering ericaceous species: *Vaccinium vitis-idaea* and *Rhododendron groenlandicum*. We found that *M. albus* increased the pollinator diversity and tended to increase visitation rates to the focal native plant species compared to control sites. *Melilotus albus* facilitated greater seed production per berry in *V. vitis-idaea* when we added 120 plants compared to when we added 40 plants or in control sites. In *R. groenlandicum*, increasing numbers of *M. albus* inflorescences lowered conspecific pollen loads and percentage of flowers pollinated; however, no differences in fruit set were detected. The number of *M. albus* inflorescences had greater importance in explaining *R. groenlandicum* pollination compared to other environmental variables such as weather and number of native flowers, and had greater importance in lower quality black spruce sites than in mixed deciduous and white spruce sites for explaining the percentage of *V. vitis-idaea* flowers pollinated. Our data suggest that the identity of new pollinators attracted to the invaded sites, degree of shared pollinators between invasive and native species, and variation in resource limitation among sites are likely determining factors in the reproductive responses of boreal native plants in the presence of an invasive.

Spellman, K. V., Mulder, C. P. H., & Carlson, M. L. (2016). Effects of invasive plant patch size and distance on the pollination and reproduction of native boreal plants. *BOTANY*, 94(12), 1151–1160. <https://doi.org/10.1139/cjb-2015-0233>

Published Abstract: In pollinator-limited ecosystems in the earliest stages of the invasion process, the effects of invasive plants on the pollination and reproduction of co-flowering native plants may be particularly sensitive to the distance between native and non-native plants. Our study tests how the distance from invasive plant patches affects the pollination and reproduction of two native boreal shrubs. We established circular sites with plots of flowering *Vaccinium vitis-idaea* L. and *Rhododendron groenlandicum* (Oeder) Kron and Judd spanning from 1 to 40 m from the site center. In 2011 and 2012, we added flowering non-native *Melilotus albus* Medik. to the center of sites in small patches (40 individuals) or large patches (120 individuals) and left other sites as controls. In some cases, the effects of *M. albus* were uniform across the 40 m distance, such as the change in *V. vitis-idaea* seed production when large patches of *M. albus* were added. In other cases, relationships with distance were found, and changes in percent pollination or seed production occurred most rapidly over the first 10 m from the patch. Our data supports the hypothesis that the detectable impact an invasive species has on the pollination of native species is affected by the spatial scale over which it is evaluated.

Walker, X. J., Frey, M. D., Conway, A. J., Jean, M., & Johnstone, J. F. (2017). Impacts of fire on non-native plant recruitment in black spruce forests of interior Alaska. *PLOS ONE*, 12(2). <https://doi.org/10.1371/journal.pone.0171599>

Published Abstract: Climate change is expected to increase the extent and severity of wildfires throughout the boreal forest. Historically, black spruce (*Picea mariana* (Mill.) B.S.P.) forests in interior Alaska have been relatively free of non-native species, but the compounding effects of climate change and an altered fire regime could facilitate the expansion of non-native plants. We tested the effects of wildfire on non-native plant colonization by conducting a seeding experiment of non-native plants on different substrate types in a burned black spruce forest, and surveying for non-native plants in recently burned and mature black spruce forests. We found few non-native plants in burned or mature forests, despite their high roadside presence, although invasion of some burned sites by dandelion (*Taraxacum officinale*) indicated the potential for non-native plants to move into burned forest. Experimental germination rates were significantly higher on mineral soil compared to organic soil, indicating that severe fires that combust much of the organic layer could increase the potential for non-native plant colonization. We conclude that fire disturbances that remove the organic layer could facilitate the invasion of non-native plants providing there is a viable seed source and dispersal vector.

1C. ACROSS CANADA: RELEVANT STUDIES OF NON-NATIVE PLANTS (BOREAL & ARCTIC)

The publications included in this section include a number of studies on the factors governing non-native plant distributions in boreal and arctic regions across Canada, as well as a few studies of how non-native plants may impact native plant communities. Surveys in boreal forest and arctic regions reveal widespread presence of non-native plants in natural habitats, often facilitated by human or natural disturbance (Wein et al. 1992, Rose & Hermanutz 2004, Sumners & Archibold 2007, Kent et al. 2018). Several studies in boreal forest highlight the strong effects and wide distribution of the invasive forage grass, smooth brome (*Bromus inermis*) (Sumners & Archibold 2007, Carrigy et al. 2016, Stoltz et al. 2017 & 2019), which is currently also a widespread invasive species in Yukon. From Alberta and elsewhere, several studies also highlight strong impacts of invasion by the woody shrub *Carragana arborescens* (Henderson & Chapman 2006, Mandryk & Wein 2006, Shortt & Vamosi 2012), a species that could become problematic in Yukon in the future.

Carrigy, A., Stotz, G., Dettlaff, M., Pec, G., Inderjit, Erbilgin, N., & Cahill, J. (2016). Community-level determinants of smooth brome (*Bromus inermis*) growth and survival in the aspen parkland. *PLANT ECOLOGY*, 217(11), 1395–1413. <https://doi.org/10.1007/s11258-016-0642-5>

Published Abstract: During the initial establishment phase, both biotic and abiotic conditions of the resident community can be important in determining the persistence of invasive plant populations. Invaders may act as passengers by tracking variation in environmental conditions (passenger model), or alternatively, may drive changes in environmental conditions which facilitate their continued invasion (driver model). We distinguish between these two models by comparing variation in resource availability among multiple plant community types to invader initial growth and survival. This study took place in the aspen parkland ecoregion of Alberta, Canada, which is a savanna-type habitat consisting of multiple plant community types and invaded by nonnative smooth brome (*Bromus inermis*). We characterized four community types by a suite of biotic and abiotic variables (brome seed density, plant richness, plant cover, soil pH, soil moisture, and organic and inorganic N) and performed a brome seed addition experiment. Brome seedling growth and survival were greater with increased levels of soil moisture, while growth decreased with increases in dissolved organic N, but did not vary with other environmental conditions. Both survival and growth of brome seedlings were lowest in brome-dominated areas. These results show support for the passenger model of invasion, as variation in local environmental conditions were associated with variation in brome performance. Further, brome appears to have a negative effect on its own growth, a pattern uncommon among plant

invaders.

Henderson, D. C., & Chapman, R. (2006). *Caragana arborescens* invasion in Elk Island National Park, Canada. *NATURAL AREAS JOURNAL*, 26(3), 261–266. [https://doi.org/10.3375/0885-8608\(2006\)26\[261:CAIIEI\]2.0.CO;2](https://doi.org/10.3375/0885-8608(2006)26[261:CAIIEI]2.0.CO;2)

Published Abstract: Siberian pea shrub, or caragana, (*Caragana arborescens* Lam.), was intentionally introduced on the northern Great Plains of North America for erosion control and ornamental hedgerows, but has invaded the understory of native deciduous forests. Although this species is widespread, there is little information on the ecology of naturalized populations or impacts of invasion. Our objectives were to describe the demographic structure of an invasive population and changes in shrub community diversity along a gradient of caragana density in an upland aspen (*Populus tremuloides* Michx.) forest at Elk Island National Park, Alberta, Canada. This caragana population spread through the understory and increased from 50 to approximately 60,000 individuals over 75 years. More than 85% of individuals were immature (< 10 yrs, < 1 m tall, non-flowering), and the size class–frequency distribution best fit a negative power function curve. Several native shrub species, including the dominant beaked hazel (*Corylus cornuta* Marsh.), were negatively associated with caragana, and the relationship between diversity and caragana density was quadratic. Control efforts will require perseverance since immature pea shrubs are difficult to locate beneath the dense growth of beaked hazel and the immature phase can last a decade.

Kent, A., Drezner, T. D., & Bello, R. (2018). Climate warming and the arrival of potentially invasive species into boreal forest and tundra in the Hudson Bay Lowlands, Canada. *POLAR BIOLOGY*, 41(10), 2007–2022. <https://doi.org/10.1007/s00300-018-2341-2>

Published Abstract: As the extremity of Arctic climate lessens with global warming, the risk of invasion increases. We assess the presence of introduced plant species and their persistence (since the previous survey) in a Canadian subpolar site on the Hudson Bay with a history of human introductions from large-scale grain inputs. Widespread sampling was done to locate all introduced plant species in the Churchill, MB, Canada area. We quantified edaphic variations through soil sampling, and the effect of aspect on introduced species' richness, cover, and height. At the regional scale, species life history traits and climate envelopes (average and variability of climate in a native range) were established to determine if persistent plant species had similar climate requirements. We found that despite statistically significant warming and increased precipitation, the number of introduced plant species in sub-Arctic Churchill declined from 80 to 36 between the 1989 and 2013 sampling periods. We found that introduced species favor locally warmer, human-disturbed sites with above average soil nutrients. The plant species that remained

in Churchill since the 1989 survey compared to those that did not persist are better able to tolerate colder temperatures and have wider, more variable climate envelopes. The decline in introduced species is likely linked to changes in grain shipment inputs. Many of the introduced species recorded in 1989 may have only existed through constant seed subsidies from imports, suggesting that most species have not yet been successful in the absence of human modification. Although the number of introduced plants has decreased, we suggest that continuous disturbance is no longer required for some introduced species to persist suggesting that a climate threshold may have been crossed for some species. One introduced species (*Taraxacum officinale*, common dandelion) has spread to areas that have not been modified by humans and is now growing in two undisturbed locations. Its current distribution outside disturbed areas does not yet warrant the distinction of invasive at this time. The findings of this study suggest that in the Canadian Arctic, if disturbance and nutrient enrichment are reduced, the potential for introduced plants to establish and possibly become invasive is still limited but will likely change as warming continues.

Mandryk, A. M., & Wein, R. W. (2006). Exotic vascular plant invasiveness and forest invasibility in urban boreal forest types. *BIOLOGICAL INVASIONS*, 8(8), 1651–1662.
<https://doi.org/10.1007/s10530-005-5874-6>

Published Abstract: The riverine forests of the northern city of Edmonton, Alberta, Canada display strong resilience to disturbance and are similar in species composition to southern boreal mixedwood forest types. This study addressed questions such as, how easily do exotic species become established in urban boreal forests (species invasiveness) and do urban boreal forest structural characteristics such as, native species richness, abundance, and vertical vegetation layers, confer resistance to exotic species establishment and spread (community invasibility)? Eighty-four forest stands were sampled and species composition and mean percent cover analyzed using ordination methods. Results showed that exotic tree/shrub types were of the most concern for invasion to urban boreal forests and that exotic species type, native habitat and propagule supply may be good indicators of invasive potential. Native forest structure appeared to confer a level of resistance to exotic species and medium to high disturbance intensity was associated with exotic species growth and spread without a corresponding loss in native species richness. Results provided large-scale evidence that diverse communities are less vulnerable to exotic species invasion, and that intermediate disturbance intensity supports species coexistence. From a management perspective, the retention of native species and native forest structure in urban forests is favored to minimize the impact of exotic species introductions, protect natural succession patterns, and minimize the spread of exotic species.

Rose, M., & Hermanutz, L. (2004). Are boreal ecosystems susceptible to alien plant invasion? Evidence from protected areas. *OECOLOGIA*, 139(3), 467–477. <https://doi.org/10.1007/s00442-004-1527-1>

Published Abstract: Although biological invasion by alien species is a major contributor to loss of indigenous biological diversity, few studies have examined the susceptibility of the boreal biome to invasion. Based on studies of other ecosystems, we hypothesized that alien plants will be restricted to disturbed areas near human activity and will not be found in natural areas of boreal ecosystems in Gros Morne National Park (Canada), a protected area experiencing a wide range of disturbance regimes. The distribution of alien plants in the region was evaluated using surveys, and study sites were established in naturally and anthropogenically disturbed habitats that had been invaded. Within study sites, randomization tests evaluated the importance of disturbance to alien plant invasion by examining changes in environmental conditions and species abundance within various disturbance regimes, while the importance of site characteristics limiting the distribution of alien plants were examined using Canonical Correspondence Analysis. Consistent with studies in a variety of biomes, areas of high disturbance and human activity had the greatest abundance of resources and the highest percentage of alien species. However, contrary to our hypothesis, natural areas of boreal ecosystems were found susceptible to alien plant invasion. Vegetation types vulnerable to invasion include forests, riparian areas, fens, and alpine meadows. Natural disturbance occurring in these vegetation types caused increases in bare ground and/or light availability facilitating alien plant invasion. Although high soil pH was associated with alien plants in these areas, disturbance was not found to cause changes in soil pH, suggesting susceptibility to invasion is pre-determined by bedrock geology or other factors influencing soil pH. Moose (*Alces alces*), a non-native herbivore, acts as the primary conduit for alien plant invasion in GMNP by dispersing propagules and creating or prolonging disturbance by trampling and browsing vegetation. The recurrent nature of disturbance within the boreal biome and its interaction with site conditions and herbivores enables alien plants to persist away from areas of high human activity. Managers of natural lands should monitor such interactions to decrease the invasion potential of alien plants.

Shortt, K. B., & Vamosi, S. M. (2012). A review of the biology of the weedy Siberian peashrub, *Caragana arborescens*, with an emphasis on its potential effects in North America. *BOTANICAL STUDIES*, 53(1), 1–8.

Published Abstract: The introduction and establishment of non-native species has been recognized as one of the most significant threats to the maintenance of native biodiversity in most taxa, including angiosperms. The Siberian peashrub, *Caragana arborescens* Lam. (Fabaceae), is native to Eurasia, but was introduced to North America in the mid-1700s. In the past 250 years, the species has become established in almost all of Canada, and approximately half of the states in the USA. However, the literature on its potential effects on native ecosystems is relatively sparse and scattered. To complement the Caragana Control Trials Project initiated by the City of

Calgary (Alberta, Canada) in 2009, we review the biology, ethnobotany, ecosystem effects, and candidate control methods of *C. arborescens*. Perhaps unsurprisingly, we find evidence for both positive and negative effects and uses of *C. arborescens*. We caution that continued habitat degradation and climate change may facilitate *C. arborescens* becoming an invasive or noxious species in more areas with time. Finally, we advocate that more attention be paid to *C. arborescens* throughout its range, with special focus on habitat fragments, recently deforested areas, and wetlands impacted by human activities.

Stotz, G. C., Gianoli, E., Patchell, M. J., & Cahill, J. F., Jr. (2017). Differential responses of native and exotic plant species to an invasive grass are driven by variation in biotic and abiotic factors. *JOURNAL OF VEGETATION SCIENCE*, 28(2), 325–336. <https://doi.org/10.1111/jvs.12499>

Published Abstract: Questions: The impact of invasive species on community structure and function varies, yet it is difficult to predict. Different hypotheses have been proposed to predict invasive species establishment and impact on resident communities, based on characteristics of the resident community and/or environmental conditions. Invasive species, however, interact with both native and exotic species. The interaction with exotic species is important, as it can result in secondary invasion or greater impact on native species. Smooth brome (*Bromus inermis* Leyss.) is a widely planted forage crop, but also a harmful invasive species in North American grasslands, yet little is known about the variability of its impact on resident communities. We ask (1) whether smooth brome has a consistent impact on community structure and function; (2) which biotic and abiotic conditions are associated with smooth brome's impact on resident communities; and (3) whether smooth brome has a similar impact on native and exotic species, and which biotic or abiotic conditions drive the interaction of smooth brome with native and exotic species. Location: Eight grasslands throughout Alberta, Canada. Methods: We used space-for-time substitutions to quantify smooth brome's impact on different aspects of community structure and function, and whether it varies depending on species richness, productivity, temperature, precipitation and variation in precipitation. Results: Smooth brome had a consistent negative impact on community structure and function. However, the strength of the effect depended on aspects of the local community. Smooth brome impacts on species richness were higher in species-rich areas, while impact on resident species biomass was larger in productive, warmer and more variable sites. In most sites the negative effect of smooth brome on species richness was higher for native species, compared to exotics. Impact on native and exotic species richness was larger in species-rich and more variable sites, respectively. Conclusions: Understanding and predicting smooth brome's impact on community structure and function can help managers prescribe management plans to reduce negative impacts of smooth brome on native communities. Predicting the interaction of smooth brome with exotic species may be just as important when planning management strategies, to avoid secondary invasion and/or the accumulation of exotic species.

Stotz, G. C., Gianoli, E., & Cahill, J. F., Jr. (2019). Biotic homogenization within and across eight widely distributed grasslands following invasion by *Bromus inermis*. *ECOLOGY*, 100(7).
<https://doi.org/10.1002/ecy.2717>

Published Abstract: Invasive species can alter the structure and function of the communities they invade, as well as lead to biotic homogenization across their invasive range, thus affecting large-scale diversity patterns. The mechanisms by which invasive species can lead to biotic homogenization are poorly understood. We argue that invasive species acting as strong, deterministic, and consistent filters within and across invaded communities are likely to cause biotic homogenization at multiple spatial scales. We studied *Bromus inermis* Leys. invasion into eight grasslands covering most of the grassland and parkland natural regions of Alberta (western Canada). Specifically, we tested whether *B. inermis* (1) has a strong impact on species richness and composition, (2) consistently alters resources (nutrients, light, and soil moisture), imposing the same ecological filter to species establishment and persistence across sites, and hence (3) whether it leads to biotic homogenization within and across sites. We recorded plant cover and resources across native-to-invaded transition areas combining space-for-time substitutions with time-series data analyses. *Bromus inermis* invasion was associated with rapid biotic homogenization of communities, within and among the eight grasslands. The sharp changes in species relative abundances following invasion was the initial driver of biotic homogenization, and species loss was delayed. Supporting the idea that biotic homogenization can occur when an invasive species presents a broad and consistent filter, resources modified by *B. inermis* invasion (particularly light and certain nutrients) were altered rather consistently within and across sites. The 50% reduction in light was likely the initial driver of biotic homogenization, and the increase in nutrient availability probably facilitates the displacement of species from the invaded areas and could lead to the establishment of self-reinforcing dynamics. Overall, our results support the idea that invaders acting as strong, deterministic, and consistent ecological filters are likely to cause biotic homogenization of the communities they invade.

Summers, W. H., & Archibold, O. W. (2007). Exotic plant species in the southern boreal forest of Saskatchewan. *FOREST ECOLOGY AND MANAGEMENT*, 251(3), 156–163.
<https://doi.org/10.1016/j.foreco.2007.06.001>

Published Abstract: Exotic species possess abilities to harm the ecosystems they invade. This study assesses the density, frequency and cover of exotic plants in roadside right-of-ways, logged areas and wildfire sites within mixedwood sections of the southern boreal forest of Saskatchewan. A total of 23 exotic species were observed including nine species of Gramineae, seven species of Leguminosae and five species of Compositae. Average density of exotic species in areas recently disturbed by timber harvesting or wildfire was 0.2 stems m⁻² with a frequency of 72%. Exotic species adapted for wind dispersal were best represented including common dandelion (*Taraxacum officinale*), perennial sow thistle (*Sonchus arvensis*) and annual hawkbeard (*Crepis tectorum*). Only two exotic species, *T. officinale* and Canada bluegrass (*Poa compressa*), were

observed in mature forests both occurred with a frequency of 13% and an average density of 0.002 Stems m⁻². A total of 22 exotic species was found in the right-of-ways quadrats with an average density of 117 Stems m⁻² and a frequency of 94%. The most frequently observed exotic species in the roadside right-of-way areas were *T. officinale*, alsike clover (*Trifolium hybridum*), *S. arvensis*, creeping red fescue (*Festuca rubra*) and smooth brome grass (*Bromus inermis*). These species are either common agricultural weeds or were part of the original seed mixture used to establish a plant cover in the roadside right-of-ways. Each of the exotic species observed was ranked to determine its current and potential threat to ecosystem attributes. The majority were considered a lesser threat and easy to control, with eight species ranked as a lesser threat and hard to control, and one species, *B. inermis*, ranked as a serious threat and hard to control. The distribution of exotic species was closely related to the management of roadside right-of-ways, wildfire events and timber harvesting. An increased distribution of exotic species was observed within roadside right-of-ways areas which had been subjected to more intensive management. Although the exotic species observed in this study are maintained and dispersed by management activities, the majority of exotic species are not a threat to this forest ecosystem in the southern boreal forest of Saskatchewan.

Trepanier, K. E., Burton, B., & Pinno, B. D. (2021). Do weeds hinder the establishment of native plants on a reclaimed North American boreal mine site? *DIVERSITY-BASEL*, 13(2). <https://doi.org/10.3390/d13020076>

Published Abstract: The majority of plant diversity in the boreal forest of northern Alberta, Canada is comprised of native understory plant species that are continuously facing competition from other species, including both undesirable native and weedy species. In oil sands mine reclamation, cover soils rich in organic matter are used to cap overburden materials. The aim of this study is to understand the role of weeds on different reclamation cover soils (forest floor-mineral mix and peat-mineral mix) and determine if they hinder the establishment of the native plant community. This study was conducted four growing seasons after site establishment in June 2019. At that time, both soil types had approximately 45% total cover, had 21 species per plot, and were composed of mainly native vegetation. Competition from non-native forbs (11% average cover, mainly *Sonchus arvensis* and *Melilotus alba*) did not seem to impact the development of the native vegetation community on either soil type given the high cover and richness of native forbs. However, native graminoids (predominantly *Calamagrostis canadensis*) were associated with reduced native forb cover and richness at graminoid cover greater than 17%. Overall, non-native forbs appeared to have little impact on the native forb community on either soil type while native graminoids had a negative influence. We suggest that the classification of what is considered an undesirable weedy species should be evaluated in the context of ecosystem management goals rather than simply the presence of non-native species.

Wein, R., Wein, G., Bahret, S., & Cody, W. (1992). Northward invading nonnative vascular plant-species in and adjacent to Wood Buffalo National Park, Canada. *CANADIAN FIELD-NATURALIST*, 106(2), 216–224. *PDF not available.

Published Abstract: A survey of the non-native vascular plant species in Wood Buffalo National Park, Canada's largest forested National Park, documented their presence and abundance in key locations. Most of the fifty-four species (nine new records) were found in disturbed sites including roadsides, settlements, farms, areas of altered hydrological regimes, recent burns, and intensive bison grazing. Species that have increased most in geographic area and abundance in recent years include *Agropyron repens*, *Bromus inermis*, *Chenopodium album*, *Melilotus spp.*, *Trifolium spp.*, *Plantago major*, *Achillea millefolium*, *Crepis tectorum* and *Sonchus arvensis*. An additional 20 species, now common in the Peace River and Fort Vermilion areas, have the potential to invade the Park if plant communities are subjected to additional stress as northern climates are modified by the greenhouse effect and as other human-caused activities disturb the vegetation. It is recommended that permanent plots be located in key locations and monitored for species invasion and changing abundances as input to management plans.

2. TERRESTRIAL ANIMALS AND ASSOCIATED DISEASES OR PARASITES

2A. YUKON STUDIES OF TERRESTRIAL WILDLIFE

Studies of terrestrial animals in Yukon Territory to date are largely focused on introduced ungulates and expanding mammal populations and their associated diseases. The following is a summary of key observations from these Yukon studies:

A. Natural range expansions and species introductions or rewilding

- a. A broad synthesis of Yukon food webs based extensively on data from Kluane (SW Yukon) suggests that species introductions of bison and elk in Yukon, as well as range expansions of mule deer, mountain lions, and American marten have had relatively small impacts on Yukon ecosystems. The largest impacts currently apparent are associated with changes in vegetation structure that appear to be affecting predation efficiency on small mammals (Boonstra et al. 2018). Range expansion of marten may be implicated in some small mammal declines or shifts in population peaks (Krebs et al. 2019).
- b. Impacts of introduced bison and elk on native Yukon ungulates appear to be relatively low. There is little evidence for spatial overlap or avoidance of bison with sheep, moose, or caribou in SW Yukon (Jung et al. 2015a, 2018). Dietary overlap is also minimal except for overlap between bison and thinhorn sheep or semi-feral horses (Jung et al. 2015b).
- c. Further expansion of introduced elk populations in southern Yukon may be limited by low forage availability and energetic costs of cold winters (Strong et al. 2013).
- d. Strategies for managing introduced species such as bison may benefit substantially from participatory engagement of diverse stakeholders around problems identified with non-native species, as demonstrated in the SW Yukon (Clark et al. 2016).
- e. Red foxes that have moved into northern habitats such as Herschel Island, Yukon appear to represent natural range expansions rather than introductions of European foxes, based on genetic information (Berteaux et al. 2015). This range expansion appears to be relatively stable over the past 40 years, with little evidence that red foxes are excluding arctic foxes on the Yukon North Slope (Gallant et al. 2012).

B. Disease interactions

- a. There is likely to be a substantial gradient in caribou susceptibility to chronic wasting disease across the Yukon, as samples from the Porcupine caribou herd show a high frequency of genetic alleles associated with disease resistance, while caribou near Atlin, BC show a very low prevalence of the same genes (Arifin et al. 2020).
- b. Recent research confirms that populations of winter tick are completing a full life cycle in southern Yukon, likely representing a natural range expansion of this parasite that may affect the health of Yukon ungulates (Chenery et al. 2020). Based on genetic evidence, the origin of winter ticks may have been an introduction from a disjunct population in Alberta or natural expansion from northern Alberta and British Columbia (Leo et al. 2014).
- c. At the moment, populations of introduced wood bison in SW Yukon appear to be free of disease organisms causing bovine tuberculosis and brucellosis (Harms et al. 2019).

Arifin, M. I., Staskevicius, A., Shim, S. Y., Huang, Y.-H., Fenton, H., McLoughlin, P. D., Mitchell, G., Cullingham, C., I., & Gilch, S. (2020). Large-scale prion protein genotyping in Canadian caribou populations and potential impact on chronic wasting disease susceptibility. *MOLECULAR ECOLOGY*, 29(20), 3830–3840. DOI: <https://doi.org/10.1111/mec.15602>

Published Abstract: Polymorphisms within the prion protein gene (Prnp) are an intrinsic factor that can modulate **chronic wasting disease (CWD)** pathogenesis in cervids. Although wild European reindeer (*Rangifer tarandus tarandus*) were infected with CWD, as yet there have been no reports of the disease in **North American caribou (*R. tarandus spp.*)**. Previous Prnp genotyping studies on approximately 200 caribou revealed single nucleotide polymorphisms (SNPs) at codons 2 (V/M), 129 (G/S), 138 (S/N), 146 (N/n) and 169 (V/M). The impact of these polymorphisms on CWD transmission is mostly unknown, except for codon 138. Reindeer carrying at least one allele encoding for asparagine (138NN or 138SN) are less susceptible to clinical CWD upon infection by natural routes, with the majority of prions limited to extraneural tissues. We sequenced the Prnp coding region of two caribou subspecies (n = 986) from British Columbia, Saskatchewan, **Yukon [Porcupine Caribou Herd and Atlin, BC]**, Nunavut and the Northwest Territories, to identify SNPs and their frequencies. Genotype frequencies at codon 138 differed significantly between barren-ground (*R. t. groenlandicus*) and woodland (*R. t. caribou*) caribou when we excluded the Chinchaga herd ($p < .05$). We also found new variants at codons 153 (Y/F) and 242 (P/L). Our findings show that the 138N allele is rare among caribou in areas with higher risk of contact with CWD-infected species. As both subspecies are classified as Threatened and play significant roles in North American Indigenous culture, history, food security and the economy, determining frequencies of Prnp genotypes associated with

susceptibility to CWD is important for future wildlife management measures.

Berteaux, D., Gallant, D., Sacks, B. N., & Statham, M. J. (2015). Red foxes (*Vulpes vulpes*) at their expanding front in the Canadian Arctic have indigenous maternal ancestry. *POLAR BIOLOGY*, 38(6), 913–917. <https://doi.org/10.1007/s00300-015-1647-6>

Published Abstract: The **red fox (*Vulpes vulpes*)** expanded its distribution over large parts of the Canadian Arctic during the twentieth century and is now considered a threat to the arctic fox (*Vulpes lagopus*). Some authors have proposed that the European red fox, introduced in Eastern North America during the eighteenth century, may have spread and caused the species' expansion in the Arctic. Assessing the biological origin of red foxes in the Nearctic is critical to determine whether their presence constitutes a case of an invading exotic species. We analyzed genetic material obtained from four red foxes at **Herschel Island (Yukon)** and Bylot Island (Nunavut), at the northern expanding front of the species. Samples from Bylot provide the northernmost genetic information on red fox obtained worldwide. We identified mitochondrial DNA haplotypes in red foxes from both Arctic locations that were phylogenetically divergent from those in Eurasia, but shared with neighboring indigenous North American populations. Thus, our results indicate that the twentieth century expansion of red foxes in the Canadian Arctic involved nearby populations potentially benefiting from habitat changes, rather than an exotic species invading new habitats.

Boonstra, R., Boutin, S., Jung, T. S., Krebs, C. J., & Taylor, S. (2018). Impact of rewilding, species introductions and climate change on the structure and function of the Yukon boreal forest ecosystem. *INTEGRATIVE ZOOLOGY*, 13(2), 123–138. <https://doi.org/10.1111/1749-4877.12288>

Published Abstract: Community and ecosystem changes are happening in the pristine boreal forest ecosystem of the **[SW] Yukon** for 2 reasons. First, climate change is affecting the abiotic environment (temperature, rainfall and growing season) and driving changes in plant productivity and predator-prey interactions. Second, simultaneously change is occurring because of mammal species reintroductions and rewilding. The key ecological question is the impact these faunal changes will have on trophic dynamics. Primary productivity in the boreal forest is increasing because of climatic warming, but plant species composition is unlikely to change significantly during the next 50-100 years. The 9-10-year population cycle of snowshoe hares will persist but could be reduced in amplitude if winter weather increases predator hunting efficiency. Small rodents have increased in abundance because of increased vegetation growth. Arctic ground squirrels have disappeared from the forest because of increased predator hunting efficiency

associated with shrub growth. Reintroductions have occurred for 2 reasons: human reintroductions of large ungulates and natural recolonization of mammals and birds extending their geographic ranges. The deliberate rewilding of wood bison (*Bison bison*) and elk (*Cervus canadensis*) has changed the trophic structure of this boreal ecosystem very little. The natural range expansion of mountain lions (*Puma concolor*), mule deer (*Odocoileus hemionus*) and American marten (*Martes americana*) should have few ecosystem effects. Understanding potential changes will require long-term monitoring studies and experiments on a scale we rarely deem possible. Ecosystems affected by climate change, species reintroductions and human alteration of habitats cannot remain stable and changes will be critically dependent on food web interactions.

Chenery, E. S., Harms, N. J., Mandrak, N. E., & Molnar, P. K. (2020). First records of *Dermacentor albipictus* larvae collected by flagging in Yukon, Canada. *PARASITES & VECTORS*, 13(1). <https://doi.org/10.1186/s13071-020-04425-3>

Published Abstract: Background: The **winter tick (*Dermacentor albipictus*)** has garnered significant attention throughout North America for its impact on wildlife health, and especially for **moose (*Alces alces*)**, where high tick burdens may result in host hair loss, anemia, and can prove fatal. The environmental transmission of *D. albipictus* larvae to a host is a critical event that has direct impact on infestation success, yet in-field observations of this life stage are lacking. In Yukon, Canada, *D. albipictus* had previously been found on hosts, but its larval life stage had not been detected in the field, despite previous sampling attempts. Methods: We sampled for *D. albipictus* larvae using traditional flagging methods in **Ibex Valley and Braeburn, Yukon**. Sites were sampled repeatedly for *D. albipictus* larvae by flagging from late August to end of October in 2018 and late August to end of November 2019. Results: Larvae of *D. albipictus* were collected throughout Ibex Valley, at approximate densities ranging from 0.04 to 4236 larvae/100 m². Larvae were present primarily on grassy vegetation on south-facing slopes in the Ibex Valley region and in Braeburn. Highest average larval numbers suggest peak questing activity was towards the end of September and beginning of October, as elsewhere in North America. Conclusions: To the best of our knowledge, we report the first successful collection of the off-host, larval life stage of *D. albipictus* by flagging, north of 60 degrees latitude in Yukon, Canada. These new observations provide critical information on the spatial distribution of the host-seeking life stage of *D. albipictus* and confirm that this species is completing its whole life cycle in southern Yukon. Understanding the environmental conditions where larvae spend their vulnerable period off-host in this northern location can inform both management strategies and projections of future range expansion which may occur with a changing climate.

Clark, D. A., Workman, L., & Jung, T. S. (2016). Impacts of reintroduced bison on First Nations People in Yukon, Canada: Finding common ground through participatory research and social learning. *CONSERVATION & SOCIETY*, 14(1), 1–12. <https://doi.org/10.4103/0972-4923.182798>

Published Abstract: From 1988-1992 **wood bison (*Bison bison athabascae*)** were transplanted to the **southwest Yukon**, inadvertently creating concerns among local First Nations about their impacts on other wildlife, habitat, and their members' traditional livelihoods. To understand these concerns we conducted a participatory impact assessment based on a multistage analysis of existing and new qualitative data. We found wood bison had since become a valued food resource, though there was a socially-determined carrying capacity for this population. Study participants desire a population large enough to sustainably harvest but avoid crossing a threshold beyond which bison may alter the regional ecosystem. An alternative problem definition emerged that focuses on how wildlife and people alike are adapting to the observed long-term changes in climate and landscape; suggesting that a wider range of acceptable policy alternatives likely exists than may have previously been thought. Collective identification of this new problem definition indicates that this specific assessment acted as a social learning process in which the participants jointly discovered new perspectives on a problem at both individual and organisational levels. Subsequent regulatory changes, based on this research, demonstrate the efficacy of participatory impact assessment for ameliorating human-wildlife conflicts.

Gallant, D., Slough, B. G., Reid, D. G., & Berteaux, D. (2012). Arctic fox versus red fox in the warming Arctic: Four decades of den surveys in north Yukon. *POLAR BIOLOGY*, 35(9), 1421–1431. <https://doi.org/10.1007/s00300-012-1181-8>

Published Abstract: During the last century, the **red fox (*Vulpes vulpes*)** has expanded its distribution into the Arctic, where it competes with the arctic fox (*Vulpes lagopus*), an ecologically similar tundra predator. The red fox expansion correlates with climate warming, and the ultimate determinant of the outcome of the competition between the two species is hypothesized to be climate. We conducted aerial and ground fox den surveys in the **northern Yukon (Herschel Island and the coastal mainland)** to investigate the relative abundance of red and arctic foxes over the last four decades. This region has undergone the most intense warming observed in North America, and we hypothesized that this climate change led to increasing dominance of red fox over arctic fox. Results of recent surveys fall within the range of previous ones, indicating little change in the relative abundance of the two species. North Yukon fox dens are mostly occupied by arctic fox, with active red fox dens occurring sympatrically. While vegetation changes have been reported, there is no indication that secondary productivity and food abundance for foxes have increased. Our study shows that in the western Arctic of North America, where climate warming was intense, the competitive balance between red and arctic foxes changed little in 40 years. Our results challenge the hypotheses linking climate to red fox expansion, and we discuss how climate warming's negative effects on predators may be

overriding positive effects of milder temperatures and longer growing seasons.

Harms, N. J., Jung, T. S., Andrew, C. L., Surujballi, O. P., VanderKop, M., Savic, M., & Powell, T. (2019). Health status of reintroduced wood bison (*Bison bison athabasca*): assessing the conservation value of an isolated population in Northwestern Canada. *JOURNAL OF WILDLIFE DISEASES*, 55(1), 44–53. <https://doi.org/10.7589/2017-09-235>

Published Abstract: A central goal for **reintroduced populations of threatened wood bison (*Bison bison athabasca*)** is to maintain them free of diseases of concern, particularly bovine tuberculosis (caused by *Mycobacterium bovis*) and brucellosis (caused by *Brucella abortus*). A wood bison population in **southwestern Yukon, Canada** was reintroduced into the wild in 1988, but no health assessment has been done since then. To provide an initial assessment of the health status and, hence, the conservation value of this population, we serologically tested 31 wood bison (approximately 3% of the population) for pathogens of interest and obtained histopathology results for select tissues. We found no evidence of exposure to *M. bovis* or *Brucella* spp., but antibodies were present to bovine parainfluenza virus 3, bovine coronavirus, *Leptospira interrogans*, and *Neospora caninum*, with seroprevalences of 87, 7, 61, and 7% of the tested animals, respectively. Reintroduced wood bison in southwestern Yukon may be of high value for wood bison recovery because it is a large and geographically isolated population with no bacteriologic, histopathologic, or serologic evidence of exposure to *Brucella* spp. or *M. bovis*.

Jung, T. S., Hegel, T. M., Stotyn, S. A., & Czetwertynski, S. M. (2015a). Co-occurrence of reintroduced and resident ungulates on a shared winter range in northwestern Canada. *ECOSCIENCE*, 22(1), 7–16. <https://doi.org/10.1080/11956860.2015.1047133>

Published Abstract: For interspecific competition to occur species must use the same limited resources (e.g. food, habitat) and overlap in time and space. **Bison (*Bison bison*)** were reintroduced to **southwestern Yukon, Canada**, where they are sympatric with resident caribou (*Rangifer tarandus*), moose (*Alces americanus*) and thinhorn sheep (*Ovis dalli*). Concerns from local communities regarding potential competition between reintroduced bison and resident ungulates prompted us to test their spatial distribution for co-occurrence. In late-winter, we conducted multiple aerial surveys (n = 1-5) of 12.2 km² cells (n = 779) to develop a presence-absence matrix (4 species x 779 cells) of the spatial distribution of ungulates. Randomization procedures were used to conduct a null model analysis of co-occurrence. Community-wide null model analysis indicated that community members were neither segregated nor aggregated;

rather, their spatial distribution was random because they did not differ from simulated null communities (n = 50,000). Similar analyses conducted on sub-matrices for each species pair also did not find evidence for segregation or aggregation among any species pairs except caribou and sheep, who were spatially segregated. We conclude that the overall potential for competition between reintroduced bison and resident ungulates during late-winter is low, based on spatial overlap. However, further investigations on the potential for competition among other niche dimension axes (e.g. food, habitat use) are recommended. Even though bison are reintroduced, these species had interacted for thousands of years and have probably co-evolved mechanisms to partition resources and co-exist on a shared landscape.

Jung, T. S., Stotyn, S. A., & Czetwertynski, S. M. (2015b). Dietary overlap and potential competition in a dynamic ungulate community in Northwestern Canada. *JOURNAL OF WILDLIFE MANAGEMENT*, 79(8), 1277–1285. <https://doi.org/10.1002/jwmg.946>

Published Abstract: The potential for interspecific competition for food resources is a key consideration when newly introduced ungulates occupy a shared range with resident native species. Management plans in Yukon, Canada, for **reintroduced bison (*Bison bison*) and introduced elk (*Cervus canadensis*)** called for an assessment of competition for food resources between these species and resident populations of caribou (*Rangifer tarandus*), thinhorn sheep (*Ovis dalli*), and moose (*Alces americanus*). To assess potential competition among ungulates, we examined dietary overlap of 7 ungulate species in **southwestern Yukon, Canada**. We compared diet composition at the forage class level and composite diet indices (diversity, evenness, and niche breadth) among species found at 2 elevation classes (high [1,200m ASL] and low [<1,200m ASL]) during summer and winter, using data derived from microhistological analyses of feces. Composite indices and percent of key forage classes in diets differed among ungulates during summer and winter and at both high and low elevations. Potential dietary overlap for most species pairs was low to moderate (0.07-0.60). However, for bison and thinhorn sheep at high elevations, and bison and semi-feral horses (*Equus ferus caballus*) at low elevations, it was high (0.82-0.97) during both summer and winter, indicating potential for food competition. Dietary overlap between species appeared to be based primarily on morphophysiological classification (i.e., browser-intermediate-grazer), rather than body size. Bison, horses, and sheep were all grazers. Intermediate species, such as introduced elk, had only moderate dietary overlap with several species. We concluded that the potential for competition for food resources based on dietary overlap between bison and sheep and bison and horses may be high in our study area, depending on forage availability, but for all other species pairs in our study area the potential for forage competition is low to moderate.

Jung, T. S., Czetwertynski, S. M., & Schmiegelow, F. K. A. (2018). Boreal forest titans do not clash: Low overlap in winter habitat selection by moose (*Alces americanus*) and reintroduced bison (*Bison bison*). *EUROPEAN JOURNAL OF WILDLIFE RESEARCH*, 64(3). <https://doi.org/10.1007/s10344-018-1184-z>

Published Abstract: Despite **moose** (*Alces americanus*) likely being both an ecological and cultural keystone species in the North American boreal forest, few studies have examined niche overlap between moose and other ungulates. In response to concerns from local people about the potential for competition for habitat between moose and **reintroduced bison** (*Bison bison*), and the potential for disturbance to moose by bison and bison hunters, we investigated overlap in winter habitat selection by these species in **southwestern Yukon, Canada**. We used available geo-referenced data of animal locations, and associated environmental covariates, to develop resource selection probability function (RSPF) models of early-winter and late-winter habitat selection by moose and bison. In early-winter, moose selected sub-alpine shrub-dominated habitats, whereas bison extensively selected wet sedge meadows in lowland valleys. Both species used a greater variety of habitats in late-winter, with moose selecting drainages above tree line or river valleys with deciduous forest cover, while bison selected either south-facing grassy slopes or wet sedge meadows. Given observed differences in seasonal habitat selection between moose and bison, these species are predicted to overlap on only 0.5 and 6.6% of our 12,818-km² study area during early-winter and late-winter, respectively. The lack of demonstrated winter habitat overlap between moose and reintroduced bison, coupled with low diet overlap, points to an overall low potential for competition for winter habitat between these species, or for disturbance to moose attributable to bison or bison hunters. Resource partitioning that facilitates coexistence on a shared landscape suggests that concern over the impact of reintroduced bison on resident populations of moose is likely unwarranted.

Krebs, C. J., Boonstra, R., Gilbert, B. S., Kenney, A. J., & Boutin, S. (2019). Impact of climate change on the small mammal community of the Yukon boreal forest. *INTEGRATIVE ZOOLOGY*, 14(6), 528–541. <https://doi.org/10.1111/1749-4877.12397>

Published Abstract: Long-term monitoring is critical to determine the stability and sustainability of wildlife populations, and if change has occurred, why. We have followed population density changes in the small mammal community in the boreal forest of the **southern Yukon** for 46 years with density estimates by live trapping on 3-5 unmanipulated grids in spring and autumn. This community consists of 10 species and was responsible for 9% of the energy flow in the herbivore component of this ecosystem from 1986 to 1996, but this increased to 38% from 2003 to 2014. Small mammals, although small in size, are large in the transfer of energy from plants to predators and decomposers. Four species form the bulk of the biomass. There was a shift in the dominant species from the 1970s to the 2000s, with *Myodes rutilus* increasing in relative abundance by 22% and *Peromyscus maniculatus* decreasing by 22%. From 2007 to 2018, *Myodes*

comprised 63% of the catch, *Peromyscus* 20%, and *Microtus* species 17%. Possible causes of these changes involve climate change, which is increasing primary production in this boreal forest, and an associated increase in the abundance of 3 rodent predators, **marten** (*Martes americana*), ermine (*Mustela ermine*) and coyotes (*Canis latrans*). Following and understanding these and potential future changes will require long-term monitoring studies on a large scale to measure metapopulation dynamics. The small mammal community in northern Canada is being affected by climate change and cannot remain stable. Changes will be critically dependent on food-web interactions that are species-specific.

Leo, S. S. T., Samuel, W. M., Pybus, M. J., & Sperling, F. A. H. (2014). Origin of *Dermacentor albipictus* (acari: ixodidae) on elk in the Yukon, Canada. *JOURNAL OF WILDLIFE DISEASES*, 50(3), 544–551. <https://doi.org/10.7589/2013-03-078>

Published Abstract: **Winter ticks (*Dermacentor albipictus*) on elk (*Cervus elaphus canadensis*)** have recently increased in numbers in the Yukon, Canada, potentially posing risks to other indigenous host species in the region. To evaluate the regional source of winter ticks in the Yukon, we sequenced one nuclear (ITS-2) and two mitochondrial (16SrRNA and COI) genes, and genotyped 14 microsatellite loci from 483 winter tick specimens collected across North America. We analyzed genetic variation across the geographic and host ranges of this tick species with the use of variance partitioning, Bayesian clustering, and standard population genetic analyses. Based on our results, winter ticks on elk in the Yukon could have originated either by translocation from central Alberta or by northward range expansion of more geographically proximate populations in northern Alberta and British Columbia. Although there was some genetic structuring of winter ticks on different hosts in the same region, we found little evidence of host specificity in winter ticks from five ungulate host species, suggesting that the winter ticks on elk in the Yukon could potentially become established on other locally available host species such as moose (*Alces alces*).

Strong, W. L., Chambers, J. H. S., & Jung, T. S. (2013). Range constraints for introduced elk in Southwest Yukon, Canada. *ARCTIC*, 66(4), 470–482.

Published Abstract: Forage availability, snow depths, and winter temperatures were assessed to determine if they might impose range constraints on **introduced elk (*Cervus elaphus*)** that voluntarily colonized a 95 km² area of **southwest Yukon (Canada)** in 1959. Parkland-like vegetation of stunted aspen (*Populus tremuloides*) and nonforest upland plant communities, which is atypical vegetation for a boreal forest environment, composed 30% of the colonized

area. About 95% of the area produced less than 300 kg/ha of forage, which represents poor productivity compared to more southern elk ranges. In the remaining 5%, indigenous graminoid communities produced (average +/- SD) 408 +/- 131 kg/ha of forage, exceeded only by nonindigenous roadside vegetation with 652 +/- 115 kg/ha. Data from radio-collared animals indicated that most elk occurrences (38% year-round) were associated with parkland-like vegetation, and fecal pellet groups were six times as frequent in indigenous graminoid vegetation as in forest vegetation. Late February 2011 snow depths of 41 +/- 7 cm, during a year with a below-normal snowfall, suggested a potential for reduced winter access to forage. Meteorological data from 1981-2010 indicate that one-third of winter daily minima in the study area were likely lower than -20 degrees C, a threshold below which the metabolism of an elk calf must increase to maintain its body temperature. Each-assessed habitat variable was unfavorable to elk compared with other western North American winter ranges, which may have limited the development of a more robust population in the southwestern Yukon.

2B. ALASKA STUDIES OF TERRESTRIAL WILDLIFE (ARCTIC-BOREAL)

Some studies have been carried out in Alaska on the spread or susceptibility to introduced diseases that are relevant to the consideration of invasive species in Yukon. Noteworthy observations include:

- A. Newly introduced diseases, including brucellosis, may have contributed to recently declining populations of muskox on the eastern North Slope of Alaska, however no one disease appears to have been responsible for the decline (Afema et al. 2017).
- B. Introductions of lice from dogs to native wolves in the Tanana River valley of interior Alaska appear to have been successfully controlled by an active treatment program (Gardner 2013).
- C. The spread of non-native ticks to wildlife is a concern in both Alaska and Yukon. A review of historical records of tick collections over the past century indicates several new species introductions and a case is made for continued regular monitoring of tick populations (Hahn et al. 2020).

Afema, J. A., Beckmen, K. B., Arthur, S. M., Huntington, K. B., & Mazet, J. A. K. (2017). Disease complexity in a declining Alaskan muskox (*Ovibos moschatus*) population. *JOURNAL OF WILDLIFE DISEASES*, 53(2), 311–329. <https://doi.org/10.7589/2016-02-035>

Published Abstract: The muskox (*Ovibos moschatus*) population inhabiting the eastern North Slope (ENS) of Alaska, US declined dramatically during 1999–2006, whereas populations in western Alaska (WA) were stable or increasing. To understand morbidity and mortality factors contributing to the decline, Alaska Department of Fish and Game conducted pathologic investigations of carcasses from 2005 until 2008. Additionally, archived sera from both ENS and WA muskoxen collected during 1984–92, before the documented beginning of the ENS decline; sera collected during 2000, near the beginning of the decline; and contemporary sera (from live capture–release, adult females) collected during 2006, 2007, and 2008 were analyzed to determine whether prevalence of antibody to potential pathogens differed in the two areas or changed over time. The pathogens investigated were those that were believed could cause lameness or poor reproduction or adversely affect general health. Furthermore, trace mineral levels, hemograms, and gastrointestinal parasites were evaluated in live adult females captured 2006–08. Pathologic investigations identified several comorbid conditions, including predation, polyarthritis caused by or consistent with *Chlamydophila* spp. infection, hoof lesions, copper deficiency, contagious ecthyma, verminous pneumonia, hepatic lipidosis suggestive of negative energy balance, and bacterial bronchopneumonia due to *Trueperella pyogenes* and *Bibersteinia trehalosi*. Pathogens suspected to be newly introduced in the ENS muskox population on the basis of serologic detection include bovine viral diarrhea, respiratory syncytial virus, *Chlamydophila* spp., *Brucella* spp., *Coxiella burnetii*, and *Leptospira* spp., whereas parainfluenza virus-3 antibody prevalence has increased in the WA population. Although multiple disease syndromes were identified that contributed to mortality and, in combination, likely limited the ENS muskox population, further holistic investigations of disease agents, trace mineral status, and nutritional factors in conjunction with intensive demographic and environmental analyses would provide a better understanding of factors that influence Alaskan muskox populations.

Gardner, C. L., Beckmen, K. B., Pamperin, N. J., & Del Vecchio, P. (2013). Experimental treatment of dog lice infestation in interior Alaska wolf packs. JOURNAL OF WILDLIFE MANAGEMENT, 77(3), 626–632. <https://doi.org/10.1002/jwmg.495>

Published Abstract: Biting dog lice (*Trichodectes canis*) were first detected on wolves (*Canis lupus*) in Southcentral Alaska (USA) in 1981 introduced via domestic dogs. Lice infestation expanded north via wolf dispersal to the Tanana Flats of Interior Alaska in December 2003. Effects of this ectoparasite on wolves were persistent with moderate to severe clinical signs of pediculosis lasting multiple generations. Our objectives were to evaluate the extent of lice infestation on wolves within the Tanana Flats and develop a management program that limited further transmission. We implemented a treatment method that consisted of multiple applications of oral antiparasitic ivermectin-injected baits aerially distributed at den and rendezvous sites during mid-May through August. During 2005–2010, we evaluated 1219 packs annually as part of a treatment group and 3 infested packs as a control. Infestation rates of treatment packs prior to

treatment varied from 15% in 2005 (2 of 13), 50% in 2006 (7 of 14), 24% in 2007 (4 of 17), 5% in 2008 (1 of 19), and 0% in 2009-2010 (0 of 19). We treated 50%, 71%, and 75% of the infested treatment packs during 2005-2007, respectively. All treated packs were lice-free the winter following treatment, whereas all 3 control packs remained infested. The combination of treatment and harvest successfully eliminated the local source population of lice within 3 years and we found no evidence of lice infestation within the treatment area during the last 3 years of the study. By using this treatment method, managers can eliminate dog lice infestations of wolves in areas 13,000 km². By initiating treatment promptly after detection, transmission to unexposed nearby packs can be postponed and the local source population of lice on wolves eradicated.

Hahn, M. B., Disler, G., Durden, L. A., Coburn, S., Witmer, F., George, W., Beckmen, K., & Gerlach, R. (2020). Establishing a baseline for tick surveillance in Alaska: Tick collection records from 1909-2019. *TICKS AND TICK-BORNE DISEASES*, 11(5). <https://doi.org/10.1016/j.ttbdis.2020.101495>

Published Abstract: The expanding geographic ranges of tick species that are known pathogen vectors can have implications for human, domestic animal, and wildlife health. Although Alaska is home to several hard tick species, it has historically been outside of the range of the most common medically important ticks in the contiguous United States and western Canada. To assess the status of tick species establishment in the state and to provide a baseline for tracking future change in the distribution of ticks, we reviewed and compiled historical tick records and summarized recent tick occurrence records collected through the development of the Alaska Submit-A-Tick Program and through tick drag sampling at sentinel sites in southcentral Alaska. Between 1909-2019, there were 1190 tick records representing 4588 individual ticks across 15 species in Alaska. The majority of ticks were species historically found in Alaska: *Haemaphysalis leporispalustris*, *Ixodes angustus*, *Ixodes auritulus*, *Ixodes howelli*, *Ixodes signatus*, and *Ixodes uriae*. Over half of all tick records in the state were collected in the last 10 yr. During this time, the number of tick records and the number of tick species recorded in Alaska each year has increased substantially. Between 2010-2019, there were 611 tick records representing 1921 individual ticks. The most common hosts for reported ticks were domestic animals (n = 343, 56 %) followed by small wild mammals (n = 147, 24 %), humans (n = 49, 8%), and wild birds (n = 31, 5%). Less than 5% of records (n = 25) were of unattached ticks found in the environment. Since 2007, non-native tick species have been documented in the state every year, including *Amblyomma americanum*, *Dermacentor andersoni*, *Dermacentor occidentalis*, *Dermacentor variabilis*, *Ixodes pacificus*, *Ixodes ricinus*, *Ixodes scapularis*, *Ixodes texanus*, and *Rhipicephalus sanguineus sensu lato* (s.l.). Almost half of the records (n = 68, 48 %) of non-native tick species from 2010 to 2019 represented ticks found on a host (usually a dog or a human) that had traveled outside of Alaska in the two weeks prior to collection. However, *A. americanum*, *D. variabilis*, *I. pacificus*, *I. texanus*, and *R. sanguineus* s.l. have been found on humans and domestic animals in Alaska without reported recent travel. In particular, there is evidence to suggest that there is local establishment of *R. sanguineus* s.l. in

Alaska. A tick species historically found in the state, *I. angustus* was frequently found on human and dogs, suggesting a potential role as a bridge vector of pathogens. Given the inconsistency of tick monitoring in Alaska over the past century, it is difficult to draw many conclusions from temporal trends in the data. Continued monitoring through the Alaska Submit-A-Tick Program will allow a more accurate assessment of the changing risk of ticks and tick-borne diseases in the state and provide information for setting clinical and public health guidelines for tick-borne disease prevention.

2C. WESTERN CANADA STUDIES OF TERRESTRIAL WILDLIFE (ARCTIC-BOREAL)

Studies of invasive animals and their ecosystem impacts in other parts of western Canada are useful for suggesting areas for attention in Yukon Territory. Scientific studies highlight two sets of terrestrial invasions that are of potential concern:

A. Invasive earthworms

- a. Human introductions of several earthworm species are emerging as an important factor altering boreal forest ecosystems in Alberta and elsewhere. Earthworm introductions into native forests in Alberta are associated with roads and fishing areas, suggesting dispersal by vehicles and through abandoned fishing bait (Cameron et al. 2007). Earthworm invasions were particularly associated with older roads near agricultural areas (Cameron and Bayne 2009). Once earthworms are introduced by human transport, they are capable of continued expansion by diffusive spread (Cameron and Bayne 2015).
- b. Experimental evidence shows that earthworm invasion alters soil microarthropod communities in boreal forests (Cameron et al. 2013).
- c. Furthermore, modelling studies carried out for boreal forests in Alberta indicate that carbon losses from forest soils caused by earthworm invasion may be equivalent in magnitude to carbon losses from wildfire (Cameron et al. 2015).

B. Spread of ungulate species and potential disease introductions

- a. Expansion of white-tailed deer populations northwards in NW Alberta appears to be associated with ongoing climate warming, with continued spread expected through this century (Dawe and Boutin 2016). Deer appear to benefit from human disturbances and creation of early successional habitats that support higher rates of reproduction (Fisher et al. 2021). Severe winter conditions and deep snow may temporarily reduce or restrict deer populations but these rebound quickly in favourable habitat (Fisher et al. 2020,

Laurent et al. 2021). Human disturbance activities and climate effects on winter conditions will interact to determine the future northward spread of white-tailed deer in western Canada (Dawe and Boutin 2016, Laurent et al. 2021).

- b. High mortality rates over similar periods observed for muskoxen, caribou, and moose in western Canada and Alaska could be due to the introduction of new diseases. One study investigated the possibility of recent introductions of a generalist bacterial pathogen, *Erysipelothrix rhusiopathiae*, were responsible for observed patterns of widespread mortality. Although this pathogen may have been recently introduced to muskoxen on Banks and Victoria Islands, distinct genetic lineages suggest that it is a naturally occurring disease among wildlife species in northwestern North America (Forde et al. 2016).

Cameron, E. K., Bayne, E. M., & Clapperton, M. J. (2007). Human-facilitated invasion of exotic earthworms into northern boreal forests. *ECOSCIENCE*, 14(4), 482–490.
[https://doi.org/10.2980/1195-6860\(2007\)14\[482:HIOEEI\]2.0.CO;2](https://doi.org/10.2980/1195-6860(2007)14[482:HIOEEI]2.0.CO;2)

Published Abstract: Recreational and industrial development is rapidly expanding in the boreal forest of western Canada. Concerns exist that such activity is facilitating the introduction and spread of non-native species such as exotic earthworms. The mechanisms by which earthworms are introduced and spread in forested systems are not well understood. Given the poor intrinsic dispersal abilities of earthworms, we propose 4 major introduction mechanisms: 1) abandonment of worms brought as fishing bait; 2) dispersal via vehicles; 3) dispersal via vertebrate predators; or 4) dispersal via waterways. To test these hypotheses, we sampled earthworms in forest stands near boat launches, roads, seismic lines, forest interiors, and remote shorelines of lakes in the boreal forest of northern Alberta, Canada. Boat launches and roads had a significantly higher probability of earthworm occurrence (54% of plots occupied) compared with the other locations (13% of plots occupied). Species commonly used as fishing bait occurred more often near boat launches (18% of plots occupied) than near roads alone (1% of plots occupied). These results suggest that vehicle transport and bait abandonment may both be mechanisms of earthworm introduction. The consequences of these introductions remain unclear but suggest that reduced road construction and regulations prohibiting the discarding of bait need to be considered to slow earthworm invasions.

Cameron, E. K., & Bayne, E. M. (2009). Road age and its importance in earthworm invasion of northern boreal forests. *JOURNAL OF APPLIED ECOLOGY*, 46(1), 28–36.
<https://doi.org/10.1111/j.1365-2664.2008.01535.x>

Published Abstract: Roads are an important conduit for the spread of invasive species. Road age is a key factor that could influence the susceptibility of roads to invasion as older roads are typically subject to higher cumulative levels of human disturbance and propagule pressure than younger roads. We investigated the effects of road age on the spread of non-native earthworms, which act as ecosystem engineers. We sampled earthworms and habitat variables at 98 roads in the boreal forest of Alberta, Canada, to determine the influence of road age on non-native earthworm occurrence at the landscape level. The extent and rate of local spread were also assessed at seven sites adjacent to old and young roads. Generalized estimating equations and zero-inflated negative binomial regression were used to analyze landscape- and local-level results, respectively. We used our models to create maps that predict the current and potential future extent of earthworms in north-eastern Alberta. Probability of earthworm occurrence and extent of spread increased as road age increased. Areas closer to agriculture and towards the south and west of our study area were also significantly more likely to be invaded by earthworms. Our spread model indicated that approximately 9% of the boreal forest of north-eastern Alberta is likely invaded by earthworms currently. This is projected to increase to 49% of suitable forest habitat over the next 50 years as human development intensifies in this region. Synthesis and applications. Although the effects of roads and linear features are commonly investigated in relation to native species, our results emphasize the importance of considering the impacts of linear feature creation on the spread of invasive species. We demonstrate that road age in particular can be an important factor affecting the spread of invasive species. In the boreal forest, reducing the number of roads being constructed, restricting traffic, and reclaiming temporary roads will be critical to reduce the future extent of earthworm invasions.

Cameron, E. K., Knysh, K. M., Proctor, H. C., & Bayne, E. M. (2013). Influence of two exotic earthworm species with different foraging strategies on abundance and composition of boreal microarthropods. *SOIL BIOLOGY & BIOCHEMISTRY*, 57, 334–340.
<https://doi.org/10.1016/j.soilbio.2012.07.010>

Published Abstract: In North America, many species of European earthworms have been introduced to northern forests. Facilitative or competitive interactions between these earthworm species may result in non-additive effects on native plant and animal species. We investigated the combined versus individual effects of the litter-dwelling earthworm *Dendrobaena octaedra* Savigny, 1826 and the deep-burrowing species *Lumbricus terrestris* L, 1758 on microarthropod assemblages from boreal forest soil by conducting a mesocosm experiment. Soil cores from earthworm-free areas of northern Alberta, Canada, were inoculated with *D. octaedra* alone, *L. terrestris* alone, both worm species together, or no earthworms. After 4.5 months,

microarthropods were extracted from the soil, counted, and identified to higher taxa. Oribatid mites were further identified to family and genus. Abundance of microarthropods was significantly lower in the treatment containing both species than in the no earthworm treatment and the *L terrestris* treatment. Oribatida and Prostigmata/Astigmata differed significantly among treatments and were lowest in the treatment containing both earthworm species, followed by the *D. octaedra* treatment, although post-hoc pairwise comparisons were not significant. Within the Oribatida, composition differed between the control and *L terrestris* treatments as compared to the *D. octaedra* and both-species treatments, with *Suctobelbella* and *Tectocephus* in particular having higher abundances in the control treatment. Effects of the two earthworm species on microarthropods were neither synergistic nor antagonistic. Our results indicate that earthworms can have strong effects on microarthropod assemblages in boreal forest soils. Future research should examine whether these changes have cascading effects on nutrient cycling, microbial communities, or plant growth.

Cameron, E. K., Shaw, C. H., Bayne, E. M., Kurz, W. A., & Kull, S. J. (2015a). Modelling interacting effects of invasive earthworms and wildfire on forest floor carbon storage in the boreal forest. *SOIL BIOLOGY & BIOCHEMISTRY*, 88, 189–196. <https://doi.org/10.1016/j.soilbio.2015.05.020>

Published Abstract: In forest ecosystems, earthworms and wildfire are two ecological agents that cause carbon (C) stored in the forest floor to be transferred to the atmosphere as greenhouse gases, either through heterotrophic respiration (earthworms) or through periodical combustion (wildfire). For centuries, wildfire has been an important ecological driver in the boreal forests of Canada where most fire emissions to the atmosphere originate from the forest floor. In contrast, earthworms are recent invaders, having been introduced to the Canadian boreal during the 20th century. Their spread is mainly associated with anthropogenic activities. We examined stand-level effects of earthworms and wildfire on forest floor C by adapting an earthworm-C simulation model for the boreal and using it in combination with a forest C accounting model. Because the overall impact of an invasive species depends on its areal extent, we used a spatial model of earthworm spread to calculate the total predicted change in C storage at the landscape-level following earthworm invasions in northeastern Alberta. Depending on the ecological groups of earthworms modelled in stand-level simulations, the forest floor C stock was reduced by 49.7–94.3% after 125 years, although the majority of this reduction occurred 35–40 years after initiation of the invasion. Because earthworm activities reduced the amount of forest floor C available for burning, emissions from wildfire were lower in the presence of earthworms. Spatial modelling of earthworm effects within the 5,905,400 ha Alberta Pacific Forestry Management Area projected that forest floor C stocks in the invaded stands decreased 50,875 Mg C by 2006, and 2,706,354 Mg C by 2056, compared with the same area if earthworms were not present. Loss of forest floor C averaged over the 50 year simulation was 10 g m² yr⁻¹; similar in magnitude to estimates for C loss in the Canadian boreal due to wildfire or harvesting. These results indicate effects of non-native earthworms on the forest floor should be included in predictions of forest

ecosystem C budgets to ensure accurate attribution of emissions to heterotrophic respiration versus combustion.

Cameron, E., & Bayne, E. (2015b). Spatial patterns and spread of exotic earthworms at local scales. CANADIAN JOURNAL OF ZOOLOGY, 93(9), 721–726. <https://doi.org/10.1139/cjz-2014-0197>

Published Abstract: Given the substantial impacts of non-native species on invaded systems, an understanding of the rates and spatial patterns of invasive spread is critical. Spread may vary across spatial scales, with dispersal of invasive species occurring both via diffusive spread at local sites and long-distance jump dispersal at larger scales. Research on earthworm invasions in North American forests has focused on patterns of spread across landscapes, with less examination of spread at local sites. We sampled the exotic earthworm *Dendrobaena octaedra* (Savigny, 1826) on 500 m x 500 m grids at three sites in the boreal forest of northeastern Alberta in 2006 and again in 2012–2013 to examine distributional changes over time. Earthworms spread farther from roads (the presumed site of initial introduction) over time, and spatial patterns at our sites suggest transport by vehicles and waterways are key vectors of dispersal at the local level. Spread was estimated to be occurring at a rate of at least 17.9 m/year. Our study indicates that both diffusive spread and jump dispersal of earthworms can be important at local scales and that local diffusive spread may be substantially higher than previously estimated.

Dawe, K. L., & Boutin, S. (2016). Climate change is the primary driver of white-tailed deer (*Odocoileus virginianus*) range expansion at the northern extent of its range; land use is secondary. ECOLOGY AND EVOLUTION, 6(18), 6435–6451. <https://doi.org/10.1002/ece3.2316>

Published Abstract: Quantifying the relative influence of multiple mechanisms driving recent range expansion of non-native species is essential for predicting future changes and for informing adaptation and management plans to protect native species. White-tailed deer (*Odocoileus virginianus*) have been expanding their range into the North American boreal forest over the last half of the 20th century. This has already altered predator-prey dynamics in Alberta, Canada, where the distribution likely reaches the northern extent of its continuous range. Although current white-tailed deer distribution is explained by both climate and human land use, the influence each factor had on the observed range expansion would depend on the spatial and temporal pattern of these changes. Our objective was to quantify the relative importance of land use and climate change as drivers of white-tailed deer range expansion and to predict decadal changes in white-

tailed deer distribution in northern Alberta for the first half of the 21st century. An existing species distribution model was used to predict past decadal distributions of white-tailed deer which were validated using independent data. The effects of climate and land use change were isolated by comparing predictions under theoretical no-change between decades scenarios, for each factor, to predictions under observed climate and land use change. Climate changes led to more than 88%, by area, of the increases in probability of white-tailed deer presence across all decades. The distribution is predicted to extend 100km further north across the northeastern Alberta boreal forest as climate continues to change over the first half of the 21st century.

Fisher, J. T., & Burton, A. C. (2021). Spatial structure of reproductive success infers mechanisms of ungulate invasion in Nearctic boreal landscapes. *ECOLOGY AND EVOLUTION*, 11(2), 900–911. <https://doi.org/10.1002/ece3.7103>

Published Abstract: Landscape change is a key driver of biodiversity declines due to habitat loss and fragmentation, but spatially shifting resources can also facilitate range expansion and invasion. Invasive populations are reproductively successful, and landscape change may buoy this success. We show how modeling the spatial structure of reproductive success can elucidate the mechanisms of range shifts and sustained invasions for mammalian species with attendant young. We use an example of white-tailed deer (deer; *Odocoileus virginianus*) expansion in the Nearctic boreal forest, a North American phenomenon implicated in severe declines of threatened woodland caribou (*Rangifer tarandus*). We hypothesized that deer reproductive success is linked to forage subsidies provided by extensive landscape change via resource extraction. We measured deer occurrence using data from 62 camera traps in northern Alberta, Canada, over three years. We weighed support for multiple competing hypotheses about deer reproductive success using multistate occupancy models and generalized linear models in an AIC-based model selection framework. Spatial patterns of reproductive success were best explained by features associated with petroleum exploration and extraction, which offer early-seral vegetation resource subsidies. Effect sizes of anthropogenic features eclipsed natural heterogeneity by two orders of magnitude. We conclude that anthropogenic early-seral forage subsidies support high springtime reproductive success, mitigating or exceeding winter losses, maintaining populations. Synthesis and Applications. Modeling spatial structuring in reproductive success can become a key goal of remote camera-based global networks, yielding ecological insights into mechanisms of invasion and range shifts to inform effective decision-making for global biodiversity conservation.

Fisher, J. T., Burton, A. C., Nolan, L., & Roy, L. (2020). Influences of landscape change and winter severity on invasive ungulate persistence in the Nearctic boreal forest. *SCIENTIFIC REPORTS*,

Published Abstract: Climate and landscape change are drivers of species range shifts and biodiversity loss; understanding how they facilitate and sustain invasions has been empirically challenging. Winter severity is decreasing with climate change and is a predicted mechanism of contemporary and future range shifts. For example, white-tailed deer (*Odocoileus virginianus*) expansion is a continental phenomenon across the Nearctic with ecological consequences for entire biotic communities. We capitalized on recent temporal variation in winter severity to examine spatial and temporal dynamics of invasive deer distribution in the Nearctic boreal forest. We hypothesized deer distribution would decrease in severe winters reflecting historical climate constraints, and remain more static in moderate winters reflecting recent climate. Further, we predicted that regardless of winter severity, deer distribution would persist and be best explained by early seral forage subsidies from extensive landscape change via resource extraction. We applied dynamic occupancy models in time, and species distribution models in space, to data from 62 camera traps sampled over 3 years in northeastern Alberta, Canada. Deer distribution shrank more markedly in severe winters but rebounded each spring regardless of winter severity. Deer distribution was best explained by anthropogenic landscape features assumed to provide early seral vegetation subsidy, accounting for natural landcover. We conclude that deer dynamics in the northern boreal forest are influenced both by landscape change across space and winter severity through time, the latter expected to further decrease with climate change. We contend that the combined influence of these two drivers is likely pervasive for many species, with changing resources offsetting or augmenting physiological limitations.

Forde, T. L., Orsel, K., Zadoks, R. N., Biek, R., Adams, L. G., Checkley, S. L., Davison, T., De Buck, J., Dumond, M., Elkin, B. T., Finnegan, L., Macbeth, B. J., Nelson, C., Niptanatiak, A., Sather, S., Schwantje, H. M., van der Meer, F., & Kutz, S. J. (2016). Bacterial genomics reveal the complex epidemiology of an emerging pathogen in arctic and boreal ungulates. *FRONTIERS IN MICROBIOLOGY*, 7. DOI: <https://doi.org/10.3389/fmicb.2016.01759>

Published Abstract: Northern ecosystems are currently experiencing unprecedented ecological change, largely driven by a rapidly changing climate. Pathogen range expansion, and emergence and altered patterns of infectious disease, are increasingly reported in wildlife at high latitudes. Understanding the causes and consequences of shifting pathogen diversity and host-pathogen interactions in these ecosystems is important for wildlife conservation, and for indigenous populations that depend on wildlife. Among the key questions are whether disease events are associated with endemic or recently introduced pathogens, and whether emerging strains are spreading throughout the region. In this study, we used a phylogenomic approach to address these questions of pathogen endemicity and spread for *Erysipelothrix rhusiopathiae*, an opportunistic multi-host bacterial pathogen associated with recent mortalities in arctic and boreal ungulate populations in North America. We isolated *E. rhusiopathiae* from carcasses associated with large-

scale die-offs of muskoxen in the Canadian Arctic Archipelago, and from contemporaneous mortality events and/or population declines among muskoxen in northwestern Alaska and caribou and moose in western Canada. Bacterial genomic diversity differed markedly among these locations; minimal divergence was present among isolates from muskoxen in the Canadian Arctic, while in caribou and moose populations, strains from highly divergent clades were isolated from the same location, or even from within a single carcass. These results indicate that mortalities among northern ungulates are not associated with a single emerging strain of *E. rhusiopathiae*, and that alternate hypotheses need to be explored. Our study illustrates the value and limitations of bacterial genomic data for discriminating between ecological hypotheses of disease emergence, and highlights the importance of studying emerging pathogens within the broader context of environmental and host factors.

Laurent, M., Dickie, M., Becker, M., Serrouya, R., & Boutin, S. (2021). Evaluating the mechanisms of landscape change on white-tailed deer populations. *JOURNAL OF WILDLIFE MANAGEMENT*, 85(2), 340–353. <https://doi.org/10.1002/jwmg.21979>

Published Abstract: Understanding how landscape change influences the distribution and densities of species, and the consequences of these changes, is a central question in modern ecology. The distribution of white-tailed deer (*Odocoileus virginianus*) is expanding across North America, and in some areas, this pattern has led to an increase in predators and consequently higher predation rates on woodland caribou (*Rangifer tarandus caribou*)-an alternate prey species that is declining across western Canada. Understanding the factors influencing deer distribution has therefore become important for effective conservation of caribou in Canada. Changing climate and anthropogenic landscape alteration are hypothesized to facilitate white-tailed deer expansion. Yet, climate and habitat alteration are spatiotemporally correlated, making these factors difficult to isolate. Our study evaluates the relative effects of snow conditions and human-modified habitat (habitat alteration) across space on white-tailed deer presence and relative density. We modeled deer response to snow depth and anthropogenic habitat alteration across a large latitudinal gradient (49 degrees to 60 degrees) in Alberta, Canada, using motion-sensitive camera data collected in winter and spring from 2015 to 2019. Deer distribution in winter and spring were best explained by models including both snow depth and habitat alteration. Sites with shallower snow had higher deer presence regardless of latitude. Increased habitat alteration increased deer presence in the northern portion of the study area only. Winter deer density was best explained by snow depth only, whereas spring density was best explained by both habitat alteration and the previous winter's snow depth. Our results suggest that limiting future habitat alteration or restoring habitat can alter deer distribution, thereby potentially slowing or reversing expansion, but that climate plays a significant role beyond what managers can influence.

3. AQUATIC INVASIVE SPECIES

3A. YUKON STUDIES OF AQUATIC INVASIVE SPECIES

The literature search carried out here found no published, peer-reviewed scientific studies focused on non-native aquatic species in Yukon. Local resources include a comprehensive review of the risks of aquatic species invasions for Yukon and potential management strategies (Leung and von Finster, 2016). A second unpublished report explores the potential risk of recreational boats as a vector for movement of invasive species from Alaska to Yukon waters (Knutson 2020).

Knutson, A. (2020). Are recreational boats moving aquatic invasive species between Alaskan marine waters and Yukon freshwaters through bilge water? Unpublished report for Yukon Invasive Species Council, Whitehorse, YT. 6 pp.

Summary: This report assesses the potential risk of invasive aquatic species being introduced to Yukon waters by recreational boats being moved from Alaskan coastal waters into Yukon. Transitions between ocean salt water in Alaska and fresh water in Yukon are suggested to provide a natural barrier for movement of invasive species. The report recommends cautionary management to prevent unwanted introductions by ensuring that recreational boats are drained of bilge water, rinsed, and dried prior to transport to Yukon waters.

Leung, M., & von Finster, A. (2016). Development of a framework for management of aquatic invasive species of concern for Yukon: literature review, risk assessment and recommendations. Environment Yukon, Yukon Fish and Wildlife Report MRC-14-01. 96 pp.

Summary: This report provides a detailed assessment of the potential risks of introductions of invasive aquatic species in Yukon. There is specific material focused on didymo, zebra mussels, New Zealand mud snail, waterweed, Eurasian watermilfoil, and whirling disease. Suggestions are made for continued monitoring and management activities related to potential aquatic invasive species in Yukon.

3B. ALASKA STUDIES OF AQUATIC INVASIVE SPECIES

One citation provides an interesting assessment of how recent spread of an invasive aquatic plant in Alaska, waterweed or elodea, has been facilitated by float plane transport (Schwoerer et al. 2020). The study also estimates the potential revenue costs to the tourism industry as a result of ecosystem damages caused by the invasive plant.

Schwoerer, T., Little, J. M., Schmidt, J. I., & Borash, K. W. (2020). Hitchhikers on floats to Arctic freshwater: Private aviation and recreation loss from aquatic invasion. *AMBIO*, 49(8), 1364–1376. PubMed. <https://doi.org/10.1007/s13280-019-01295-7>

Published Abstract: This study of aviation-related recreation loss shows that a survey primarily aimed at collecting information on invasive species' pathways can also be used to estimate changes in pathway-related ecosystem services. We present a case study for *Elodea* spp. (elodea), Alaska's first known aquatic invasive plant, by combining respondents' stated pre-invasion actual flights with stated post-invasion contingent behavior, plane operating costs, and site quality data. We asked pilots about the extent of continued flights should destinations become invaded and inhibit flight safety. We estimate a recreation demand model where the lost trip value to the average floatplane pilot whose destination is an elodea-invaded lake is US\$185 (95 % CI \$157, \$211). Estimates of ecosystem damages incurred by private actors responsible for transmitting invaders can nudge actors to change behavior and inform adaptive ecosystem management. The policy and modeling implications of quantifying such damages and integration into more complex models are discussed.

3C. WESTERN CANADA STUDIES OF AQUATIC INVASIVE SPECIES

Samples from Yukon lakes were used in an assessment of broad-scale patterns in aquatic zooplankton communities across western Canada, which included an assessment of the impacts of stocking by sport-fish. Variations in communities were most strongly related to environmental variables and spatial configuration, with only a very minor influence of sport-fish stocking (Loewen et al. 2019). A more detailed investigation of the impact of salmonid fish introductions on lake zooplankton focused on lakes in the Rocky and Cascade Mountains of southern Canada and northern USA, which confirmed the overriding influence of environmental variables and relatively minor effects of sportfish on zooplankton (Loewen et al. 2020).

Loewen, C. J. G., Strecker, A. L., Gilbert, B., & Jackson, D. A. (2020). Climate warming moderates the impacts of introduced sportfish on multiple dimensions of prey biodiversity. *GLOBAL CHANGE BIOLOGY*, 26(9), 4937–4951. <https://doi.org/10.1111/gcb.15225>

Published Abstract: Human-assisted introductions of exotic species are a leading cause of anthropogenic change in biodiversity; however, context dependencies and interactions with co-occurring stressors impede our ability to predict their ecological impacts. The legacy of historical sportfish stocking in mountainous regions of western North America creates a unique, natural quasiexperiment to investigate factors moderating invasion impacts on native communities across broad geographic and environmental gradients. Here we synthesize fish stocking records and zooplankton relative abundance for 685 mountain lakes and ponds in the Cascade and Canadian Rocky Mountain Ranges, to reveal the effects of predatory sportfish introduction on multiple taxonomic, functional and phylogenetic dimensions of prey biodiversity. We demonstrate an innovative analytical approach, combining exploratory random forest machine learning with confirmatory multigroup analysis using multivariate partial least-squares structural equation models, to generate and test hypotheses concerning environmental moderation of stocking impacts. We discovered distinct effects of stocking across different dimensions of diversity, including negligible (nonsignificant) impacts on local taxonomic richness (i.e. alpha diversity) and trophic structure, in contrast to significant declines in compositional uniqueness (i.e. beta diversity) and body size. Furthermore, we found that stocking impacts were moderated by cross-scale interactions with climate and climate-related land-cover variables (e.g. factors linked to treeline position and glaciers). Interactions with physical morphometric and lithological factors were generally of lesser importance, though catchment slope and habitat size constraints were relevant in certain dimensions. Finally, applying space-for-time substitution, a strong antagonistic (i.e. dampening) interaction between sportfish predation and warmer temperatures suggests redundancy of their size-selective effects, meaning that warming will lessen the consequences of introductions in the future and stocked lakes may be less impacted by subsequent warming. While both stressors drive biotic homogenization, our results have important implications for fisheries managers weighing the costs/benefits of stocking-or removing established non-native populations-under a rapidly changing climate.

Loewen, C. J. G., Strecker, A. L., Larson, G. L., Vogel, A., Fischer, J. M., & Vinebrooke, R. D. (2019). Macroecological drivers of zooplankton communities across the mountains of western North America. *ECOGRAPHY*, 42(4), 791–803. <https://doi.org/10.1111/ecog.03817>

Published Abstract: Disentangling the environmental and spatial drivers of biological communities across large scales increasingly challenges modern ecology in a rapidly changing world. Here, we investigate the hierarchical and trait-based organization of regional and local factors of zooplankton communities at a macroscale of 1240 mountain lakes and ponds spanning western North America (California, USA, to **Yukon Territory [multiple lakes], Canada**). Variation partitioning was used to test the hypothesized importance of climate, connectivity, catchment features, and exotic sportfish to zooplankton beta-diversity in the context of key functional traits (body size and reproductive dispersal potential) given the pronounced environmental heterogeneity (e.g. thermal gradients), topographic barriers, and legacy of stocked fish in mountainous regions. Dispersal limitation was inferred from multispecies patch connectivity estimates based on nearest and average distances to occupied patches. Environmental heterogeneity best explained community composition as catchment/lake features (morphometry, land cover, and lithology) collectively captured greater variation than did climate (temperature, precipitation, and solar radiation), local stocking, or connectivity; however, single climatic variables captured the most variation individually. Macrospatial variation by larger obligate sexual species was better explained than that by smaller cyclically parthenogenetic asexual species. Our results provide several novel insights into the macroecology of zooplankton of the North American Cordillera, demonstrating their stronger associations to climatically driven aquatic-terrestrial habitat coupling than dynamics arising from introduced salmonids, human land-use, or species dispersal. These findings highlight the clear and important role of these communities as bioindicators of the limnological impacts of accelerating rates of climate change, as their responses appear relatively not confounded by local human perturbations or dispersal limitation.

4. GENERAL REFERENCES ON INVASIVE SPECIES

4A. YUKON REPORTS

IES (Industrial Forestry Service Ltd). (2011). The effect of climate change on invasive species and their potential impacts in Whitehorse. Unpublished report. Yukon Invasive Species Council, Whitehorse, Yukon. 83 pp.

Summary: This report provides a summary of information intended to help managers with risk management and decision making in regards to invasive species in Yukon and the Whitehorse area in particular. The report reviews the current understanding of invasive species and their ecology in the Whitehorse area and neighbouring jurisdictions, and summarizes potential interactions with expected climate changes. Findings are presented in two parts: Part 1 provides a review and synthesis of existing literature, and Part 2 compares risk analysis procedures for invasive species developed in Alaska and British Columbia.

White, M. (2019). YESAB Assessments: Toolkit for identifying and mitigating risks related to terrestrial invasive species. Unpublished report. Government of Yukon's Department of Environment and Invasive Species Interdepartmental Working Group, Whitehorse, Yukon. 25 pp.

Summary: This report presents a toolkit designed to help those participating in the Yukon Environmental and Socioeconomic Assessment Act process, including project proponents, assessors and regulators. The aim of the toolkit is to better identify the risks of spreading terrestrial invasive species through a proposed project's activities and to choose appropriate mitigation strategies to reduce those risks. The main focus is on preventing the introduction and spread of terrestrial invasive species in Yukon Territory.

YISC. (2012). Workshop Report: Pulling together to meet the challenge of invasive species. Unpublished report. Yukon Invasive Species Council, Whitehorse, Yukon. 32 pp.

Summary: This report summarizes material presented and discussed at the 2012 workshop on invasive species held in Whitehorse. Stated goals of the workshop were to a) share knowledge and information about invasive species in the Yukon, b) expand collaboration related to invasive species by communicating and collaborating between all level of governments, researchers, professionals and the public, and c) identify solutions to address the challenges and barriers around dealing with invasive species. The report covers current understanding of Yukon invasive species, with updates on current research, and identifies key strategies for managing invasive species. It concludes with a listing of priorities and next steps for invasive species work in Yukon.

YISC. (2016). Workshop Report: Working towards managing invasive species in Yukon. Unpublished report. Yukon Invasive Species Council, Whitehorse, Yukon. 29 pp.

Summary: This report summarizes material presented and discussed at the 2016 workshop on invasive species held in Whitehorse. Objectives of the workshop were to a) review progress and lessons learned since the previous workshop in 2012, b) share knowledge and information about invasive species in the Yukon, and c) foster ongoing collaboration related to invasive species between governments, researchers, professionals and the public. The report summarizes detailed discussions held during the workshop regarding monitoring programs and specific invasive species, as well as management actions and issues.

4B. PUBLISHED LITERATURE REVIEWS AND SYNTHESSES

Invasive species are an important topic globally and there is a large amount of published scientific literature that addresses processes and patterns of species invasion across diverse habitats. References selected here were included because they presented material relevant to species invasion in boreal or arctic habitats that may carry important lessons helpful in the consideration of Yukon invasive species. Key points made on several salient topics include:

A. Forecasts of future species invasion patterns:

- a. Cold regions at high elevations and latitudes have so far been comparatively resistant to exotic plant invasions (Wasowicz et al. 2020). These systems are, however, poised to experience increased spread of invasive species as the climate warms and human activities continue to provide an increasing number of potential introductions (Alsos et al. 2015, Alexander et al. 2016, Rew et al. 2020).
 - i. In the circumpolar North, the spread of invasive plants is largely due to seed contamination and human transport (Wasowicz et al. 2020).
 - ii. Globally, northern regions are not forecasted to become hotspots of plant species invasion in the coming century (Bellard et al. 2013), and may even lose invasive species where human activities are transient (Also et al. 2015).
 - b. Northward expansion of mammal populations is expected to be widespread with climate change based on current climate conditions where these animals are found. Broad-scale models predict that the Yukon will provide suitable habitat for more southern species such as bobcat, northern flying squirrel, fisher and white-tailed deer in the coming century with climate change, and northward expansion of habitat for existing populations of black bear, lynx, marten, moose, and snowshoe hare (Deb et al. 2020).
 - i. Observational evidence from Sweden is consistent with these predictions, showing increased trends in population size and distributions of southern mammal species along with some range contractions of northern species (Elmhagen et al. 2015).
 - c. Within the boreal forests of Canada, ecosystems appear to continue to exhibit resistance to invasion except for invasion by large mammals, wildlife diseases, and earthworms. Human disturbance and transport is also highly associated with species invasions (Langor et al. 2014).
- B. Potential synergies may exist between invasive species that promote rapid changes in ecosystems.
- a. One important emerging interaction is evidence that invasion by non-native earthworms in North American forests appears to promote the abundance of non-native plants in the same ecosystems, causing declines in native biodiversity (Craven et al. 2017).
 - b. Alternatively, positive interactions between invasive plants and their pollinators may actually benefit threatened populations, as evinced by positive effects of invasive bird vetch on native bees in Ontario (Gibson et al. 2019).
- C. Lessons may be learned about the monitoring and control of invasive species in other

jurisdictions.

- a. One published study describes a decision making process and potential outcomes for management of a non-native grass in Grasslands National Park (SK), providing an example of a process that could be used elsewhere for adaptive management of non-native plants (Frid & Wilmshurst 2009).
- b. Monitoring of invasive species depends on effective survey methods. Adaptive survey methods may be used to provide efficient monitoring of non-native plant species that are spreading from roads or other point sources (Maxwell et al. 2012).
- c. Integrated weed management is an approach being used to control and reduce harmful plant invasions in other parts of Canada, and a recent paper provides a helpful review of this process (Miller et al. 2016).
 - i. Of specific relevance to Yukon, evaluation of the potential for herbicides, flaming, and mowing for controlling populations of invasive sweetclover found variable efficacy of treatments in reducing production of viable seed (Conn & Seefeldt 2009).

Alexander, J. M., Lembrechts, J. J., Cavieres, L. A., Daehler, C., Haider, S., Kueffer, C., Liu, G., McDougall, K., Milbau, A., Pauchard, A., Rew, L. J., & Seipel, T. (2016). Plant invasions into mountains and alpine ecosystems: Current status and future challenges. *Alpine Botany*, 126(2), 89–103. <https://doi.org/10.1007/s00035-016-0172-8>

Published Abstract: Recent years have seen a surge of interest in understanding patterns and processes of plant invasions into mountains. Here, we synthesise current knowledge about the spread of non-native plants along elevation gradients, emphasising the current status and impacts that these species have in alpine ecosystems. Globally, invasions along elevation gradients are influenced by propagule availability, environmental constraints on population growth, evolutionary change and biotic interactions. The highest elevations are so far relatively free from non-native plants. Nonetheless, in total nearly 200 non-native plant species have been recorded from alpine environments around the world. However, we identified only three species as specifically cold-adapted, with the overwhelming majority having their centres of distribution under warmer environments, and few have substantial impacts on native communities. A combination of low propagule availability and low invasibility likely explain why alpine environments host few non-native plants relative to lowland ecosystems. However, experiences in

some areas demonstrate that alpine ecosystems are not inherently resistant to invasions. Furthermore, they will face increasing pressure from the introduction of pre-adapted species, climate change, and the range expansion of native species, which are already causing concern in some areas. Nonetheless, because they are still relatively free from non-native plants, preventative action could be an effective way to limit future impacts of invasions in alpine environments.

Alsos, I. G., Ware, C., & Elven, R. (2015). Past Arctic aliens have passed away, current ones may stay. *BIOLOGICAL INVASIONS*, 17(11), 3113–3123. <https://doi.org/10.1007/s10530-015-0937-9>

Published Abstract: Increased human activity and climate change are expected to increase the numbers and impact of alien species in the Arctic, but knowledge of alien species is poor in most Arctic regions. Through field investigations over the last 10 years, and review of alien vascular plant records for the high Arctic Archipelago Svalbard over the past 130 years, we explored long term trends in persistence and phenology. In total, 448 observations of 105 taxa have been recorded from 28 sites. Recent surveys at 18 of these sites revealed that alien species had disappeared at half of them. Investigations at a further 49 sites characterised by former human activity and/or current tourist landing sites did not reveal any alien species. Patterns of alien species distribution suggest that greater alien species richness is more likely to be aligned with ongoing human inhabitation than sites of transient use. The probability of an alien species being in a more advanced phenological stage increased with higher mean July temperatures. As higher mean July temperatures are positively correlated with more recent year, the latter finding suggests a clear warming effect on the increased reproductive potential of alien plants, and thus an increased potential for spread in Svalbard. Given that both human activity and temperatures are expected to increase in the future, there is need to respond in policy and action to reduce the potential for further alien species introduction and spread in the Arctic.

Bellard, C., Thuiller, W., Leroy, B., Genovesi, P., Bakkenes, M., & Courchamp, F. (2013). Will climate change promote future invasions? *GLOBAL CHANGE BIOLOGY*, 19(12), 3740–3748. <https://doi.org/10.1111/gcb.12344>

Published Abstract: Biological invasion is increasingly recognized as one of the greatest threats to biodiversity. Using ensemble forecasts from species distribution models to project future suitable

areas of the 100 of the world's worst invasive species defined by the International Union for the Conservation of Nature, we show that both climate and land use changes will likely cause drastic species range shifts. Looking at potential spatial aggregation of invasive species, we identify three future hotspots of invasion in Europe, northeastern North America, and Oceania. We also emphasize that some regions could lose a significant number of invasive alien species, creating opportunities for ecosystem restoration. From the list of 100, scenarios of potential range distributions show a consistent shrinking for invasive amphibians and birds, while for aquatic and terrestrial invertebrates distributions are projected to substantially increase in most cases. Given the harmful impacts these invasive species currently have on ecosystems, these species will likely dramatically influence the future of biodiversity.

Conn, J., & Seefeldt, S. (2009). Invasive White Sweetclover (*Melilotus officinalis*) control with herbicides, cutting, and flaming. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 2(3), 270-277. <https://doi.org/10.1614/IPSM-08-118.1>

Published Abstract: White sweetclover is invading the Alaska glacial river floodplains and roadsides adjacent to natural areas, and control methods are needed. Chlorsulfuron, 2,4-DB, clopyralid, triclopyr, and 2,4-D controlled white sweetclover seedlings below recommended rates in the greenhouse. Biomass of established plants in the field was reduced by chlorsulfuron at recommended (17.6 g ai/ha), 1/2, and 1/4 rates and was reduced by triclopyr and 2,4-D at recommended rates (1,260 and 1,600 g ai/ha). Herbicides were more effective at reducing white sweetclover viable seed production in 2007 than in 2006. Only chlorsulfuron at 17.6 g ai/ha (recommended rate) eliminated seed production in both years. Flaming killed first-year plants, but some second-year plants resprouted and produced viable seed. Cutting at the 2.5 or 10 cm height did not control first-year plants because of regrowth, and second-year plant density and seed production was reduced by cutting at 2.5 cm but not by cutting at 10 cm.

Craven, D., Thakur, M. P., Cameron, E. K., Frelich, L. E., Beauséjour, R., Blair, R. B., Blossey, B., Burtis, J., Choi, A., Dávalos, A., Fahey, T. J., Fisichelli, N. A., Gibson, K., Handa, I. T., Hopfensperger, K., Loss, S. R., Nuzzo, V., Maerz, J. C., Sackett, T., ... Eisenhauer, N. (2017). The unseen invaders: Introduced earthworms as drivers of change in plant communities in North American forests (a meta-analysis). *GLOBAL CHANGE BIOLOGY*, 23(3), 1065–1074. <https://doi.org/10.1111/gcb.13446>

Published Abstract: Globally, biological invasions can have strong impacts on biodiversity as well as ecosystem functioning. While less conspicuous than introduced aboveground organisms, introduced belowground organisms may have similarly strong effects. Here, we synthesize for the first time the impacts of introduced earthworms on plant diversity and community composition in North American forests. We conducted a meta-analysis using a total of 645 observations to quantify mean effect sizes of associations between introduced earthworm communities and plant diversity, cover of plant functional groups, and cover of native and non-native plants. We found that plant diversity significantly declined with increasing richness of introduced earthworm ecological groups. While plant species richness or evenness did not change with earthworm invasion, our results indicate clear changes in plant community composition: cover of graminoids and non-native plant species significantly increased, and cover of native plant species (of all functional groups) tended to decrease, with increasing earthworm biomass. Overall, these findings support the hypothesis that introduced earthworms facilitate particular plant species adapted to the abiotic conditions of earthworm-invaded forests. Further, our study provides evidence that introduced earthworms are associated with declines in plant diversity in North American forests. Changing plant functional composition in these forests may have long-lasting effects on ecosystem functioning.

Deb, J. C., Forbes, G., & MacLean, D. A. (2020). Modelling the spatial distribution of selected North American woodland mammals under future climate scenarios. *MAMMAL REVIEW*, 50(4), 440–452. <https://doi.org/10.1111/mam.12210>

Published Abstract: North America has a diverse array of mammalian species. Model projections indicate significant variations in future climate conditions of North America, and the habitats of woodland mammals of this continent may be particularly sensitive to changes in climate. We report on the potential spatial distributions of 13 wide-ranging, relatively common species of North American woodland mammals under future climate scenarios. We examined the potential influence of the mean and seasonal climate variables on the distribution of species. Presence-only occurrence records of species, four predictor variables, two future climate scenarios (Representative Concentration Pathways 4.5 and 8.5), and two time steps (current and 2070) were used to build species' distribution models using a maximum entropy algorithm (MaxEnt). Our results suggested that overall, 11 of the 13 species are likely to gain climatically suitable space (regions where climate conditions will be similar to those of area currently occupied) at the continental scale, but American marten (*Martes americana*) and 'woodland' caribou (*Rangifer tarandus*) are likely to lose suitable climate range by 2070. Furthermore, climate space is likely to be expanding northwards under future climate scenarios for most of the mammals, and many jurisdictions in the border region between Canada and the USA are likely to lose iconic species, such as moose (*Alces alces*). We identified regions as potential in situ and ex situ climate change refugia, which are increasingly considered to be important for biodiversity conservation. The

model results suggest significant implications for conservation planning for the 13 mammalian species under global climate change, especially at fine spatial scales. Numerous species that are presently common at their southern range edge will be functionally or completely extirpated in 50 years. The potential in situ and ex situ climate change refugia could provide an effective support for adaptive strategies aimed at species conservation planning.

Diagne, C., Leroy, B., Vaissière, A.-C., Gozlan, R. E., Roiz, D., Jarić, I., Salles, J.-M., Bradshaw, C. J. A., & Courchamp, F. (2021). High and rising economic costs of biological invasions worldwide. *Nature*, 592(7855), 571–576. <https://doi.org/10.1038/s41586-021-03405-6>

Published Abstract: Biological invasions are responsible for substantial biodiversity declines as well as high economic losses to society and monetary expenditures associated with the management of these invasions. The InvaCost database has enabled the generation of a reliable, comprehensive, standardized and easily updatable synthesis of the monetary costs of biological invasions worldwide. Here we found that the total reported costs of invasions reached a minimum of US\$1.288 trillion (2017 US dollars) over the past few decades (1970–2017), with an annual mean cost of US\$26.8 billion. Moreover, we estimate that the annual mean cost could reach US\$162.7 billion in 2017. These costs remain strongly underestimated and do not show any sign of slowing down, exhibiting a consistent threefold increase per decade. We show that the documented costs are widely distributed and have strong gaps at regional and taxonomic scales, with damage costs being an order of magnitude higher than management expenditures. Research approaches that document the costs of biological invasions need to be further improved. Nonetheless, our findings call for the implementation of consistent management actions and international policy agreements that aim to reduce the burden of invasive alien species.

Elmhagen, B., Kindberg, J., Hellstrom, P., & Angerbjorn, A. (2015). A boreal invasion in response to climate change? Range shifts and community effects in the borderland between forest and tundra. *AMBIO*, 44(1, SI), 39–50. <https://doi.org/10.1007/s13280-014-0606-8>

Published Abstract: It has been hypothesized that climate warming will allow southern species to advance north and invade northern ecosystems. We review the changes in the Swedish mammal and bird community in boreal forest and alpine tundra since the nineteenth century, as well as suggested drivers of change. Observed changes include (1) range expansion and increased abundance in southern birds, ungulates, and carnivores; (2) range contraction and decline in

northern birds and carnivores; and (3) abundance decline or periodically disrupted dynamics in cyclic populations of small and medium-sized mammals and birds. The first warm spell, 1930-1960, stands out as a period of substantial faunal change. However, in addition to climate warming, suggested drivers of change include land use and other anthropogenic factors. We hypothesize all these drivers interacted, primarily favoring southern generalists. Future research should aim to distinguish between effects of climate and land-use change in boreal and tundra ecosystems.

Erid, L., & Wilshurst, J. F. (2009). Decision analysis to evaluate control strategies for crested wheatgrass (*Agropyron cristatum*) in Grasslands National Park of Canada. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 2(4), 324–336. <https://doi.org/10.1614/IPSM-09-006.1>

Published Abstract: Protected area managers often face uncertainty when managing invasive plants at the landscape scale. Crested wheatgrass, a popular forage crop in the Great Plains since the 1930s, is an aggressive invader of native grassland and a problem for land managers in protected areas where seeded roadsides and abandoned fields encroach into the native mixed-grass prairie. Given limited resources, land managers need to determine the best strategy for reducing the cover of crested wheatgrass. However, there is a high degree of uncertainty associated with the dynamics of crested wheatgrass spread and control. To compare alternative management strategies for crested wheatgrass in the face of uncertainty, we conducted a decision analysis based on information from Grasslands National Park. Our analysis involves the use of a spatially explicit model that incorporates alternative management strategies and hypotheses about crested wheatgrass spread and control dynamics. Using a decision tree and assigning probabilities to our alternative hypotheses, we calculated the expected outcome of each management alternative and ranked these alternatives. Because the probabilities assigned to alternative hypotheses are also uncertain, we conducted a sensitivity analysis of the full probability space. Our results show that under current funding levels it is always best to prioritize the early detection and control of new infestations. Monitoring the effectiveness of control is paramount to long-term success, emphasising the need for adaptive approaches to invasive plant management. This type of decision analysis approach could be applied to other invasive plants where there is a need to find management strategies that are robust to uncertainty in the current understanding of how these plants are best managed.

Gibson, S. D., Liczner, A. R., & Colla, S. R. (2019). Conservation conundrum: at-risk bumble bees (*Bombus* spp.) show preference for invasive tufted vetch (*Vicia cracca*) while foraging in protected areas. *JOURNAL OF INSECT SCIENCE*, 19(2). <https://doi.org/10.1093/jisesa/iez017>

Published Abstract: In recent decades, some bumble bee species have declined, including in North America. Declines have been reported in species of bumble bees historically present in Ontario, including: yellow bumble bee (*Bombus fervidus*) (Fabricus, 1798), American bumble bee (*Bombus pensylvanicus*) (DeGeer, 1773), and yellow-banded bumble bee (*Bombus terricola*) (Kirby, 1837). Threats contributing to bumble bee population declines include: land-use changes, habitat loss, climate change, pathogen spillover, and pesticide use. A response to the need for action on pollinator preservation in North America has been to encourage “bee-friendly” plantings. Previous studies show differences in common and at-risk bumble bee foraging; however, similar data are unavailable for Ontario. Our research question is whether there is a difference in co-occurring at-risk and common bumble bee (*Bombus* spp.) floral use (including nectar and pollen collection) in protected areas in southern Ontario. We hypothesize that common and at-risk species forage differently, predicting that at-risk species forage on a limited selection of host plants. We conducted a field survey of sites in southern Ontario, using observational methods to determine bumble bee foraging by species. The results of a redundancy analysis show a difference in foraging between common and at-risk bumblebee species. At-risk bumble bee species show a preference for foraging on invasive, naturalized *Vicia cracca* (tufted vetch). This finding raises the question of how to preserve or provide forage for at-risk bumble bees, when they show an association with an invasive species often subject to control in protected areas.

Langor, D. W., Cameron, E. K., MacQuarrie, C. J. K., McBeath, A., McClay, A., Peter, B., Pybus, M., Ramsfield, T., Ryall, K., Scarr, T., Yemshanov, D., DeMerchant, I., Footitt, R., & Pohl, G. R. (2014). Non-native species in Canada’s boreal zone: Diversity, impacts, and risk. ENVIRONMENTAL REVIEWS, 22(4), 372-+. <https://doi.org/10.1139/er-2013-0083>

Published Abstract: More than 1180 non-native species, mostly of Palaearctic origin, have been recorded from the boreal zone of Canada, with the highest diversity on the island of Newfoundland and in the southern boreal zone of Ontario and Quebec. The non-native biota of the boreal zone (and of Canada in general) is poorly known in terms of species composition and distribution. A large proportion of species are associated with disturbed anthropogenic habitats such as urban areas, agricultural landscapes, transportation and communication corridors, and industrial developments. Natural habitats in the boreal zone have a high degree of resistance to invasion compared with those of other Canadian zones, likely owing to harsh climates, low light levels, poor soil nutrient availability, low soil pH, low productivity, and dense covering of the ground by plants, especially bryophytes. Of the relatively few non-native species that have successfully colonized the boreal zone, many decline greatly in abundance after a few years, suggesting biotic resilience. To date the boreal zone has shown the least resistance and resilience to large vertebrates (moose and white-tailed deer) translocated to islands, diseases of vertebrates, and earthworms. In general, the ecological impacts of non-native species on the boreal zone have been poorly studied, and there are few examples where such impacts are evident. Likewise, there

has been little attempt to quantify the economic impacts of non-native species in either the boreal zone or in Canada as a whole. In the few cases where management measures have been implemented for highly destructive non-native species, results have been somewhat successful, especially where classical biological control measures have been implemented against insects on trees. Chemical and mechanical management measures have had only limited success in localized situations. Management resources are most effectively applied to reducing the risk of introduction. The risk to the boreal zone posed by future new non-native species is increasing with the warming climate and the fast and direct transport of goods into the boreal zone from points of origin. Five recommendations are provided to address recognized gaps concerning non-native species.

Maxwell, B. D., Backus, V., Hohmann, M. G., Irvine, K. M., Lawrence, P., Lehnhoff, E. A., & Rew, L. J. (2012). Comparison of transect-based standard and adaptive sampling methods for invasive plant species. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 5(2), 178–193.
<https://doi.org/10.1614/IPSM-D-11-00022.1>

Published Abstract: Early detection of an invading nonindigenous plant species (NIS) may be critical for efficient and effective management. Adaptive survey sampling methods may provide unbiased sampling for best estimates of distribution of rare and spatially clustered populations of plants in the early stages of invasion. However, there are few examples of these methods being used for nonnative plant surveys in which travelling distances away from an initial or source patch, or away from a road or trail, can be time consuming due to the topography and vegetation. Nor is there guidance as to which of the many adaptive methods would be most appropriate as a basis for invasive plant mapping and subsequent management. Here we used an empirical complete census of four invader species in early to middle stages of invasion in a management area to assess the effectiveness and efficiency of three nonadaptive methods, four adaptive cluster methods, and four adaptive web sampling methods that all originated from transects. The adaptive methods generally sampled more NIS-occupied cells and patches than standard transect approaches. Sampling along roads only was time-efficient and effective, but only for species with restricted distribution along the roads. When populations were more patchy and dispersed over the landscape the adaptive cluster starting at the road generally proved to be the most time-efficient and effective NIS detection method.

Miller, T. W. (2016). Integrated Strategies for Management of Perennial Weeds. *INVASIVE PLANT SCIENCE AND MANAGEMENT*, 9(2), 148–159. <https://doi.org/10.1614/IPSM-D-15-00037.1>

Published Abstract: Multiple weed control strategies employed in combination can often aid the successful management of perennial weed species. This review article provides examples of integrated control programs that could aid in the management of several invasive perennial weed species that are problematic in the Pacific Northwest and elsewhere in North America. The development of an integrated management control program for wild chervil, a relatively recent invader to the Pacific Northwest of the United States and adjacent Canada, provides an example for this process. Through use of mechanical (mowing and tillage), cultural (establishment of competitive vegetation), and chemical (specific herbicides) strategies, control of this short-lived perennial species was greatly improved as compared to foliar herbicide applications alone. Such integrated strategies have been shown to enhance control of many perennial weed species, while potentially reducing the amount of herbicide applied, lessening the possibility of injury to adjacent desirable vegetation and increasing the stability of the ecological community at the site.

Rew, L. J., McDougall, K. L., Alexander, J. M., Daehler, C. C., Essl, F., Haider, S., Kueffer, C., Lenoir, J., Milbau, A., Nunez, M. A., Pauchard, A., & Rabitsch, W. (2020). Moving up and over: Redistribution of plants in alpine, Arctic, and Antarctic ecosystems under global change. *ARCTIC ANTARCTIC AND ALPINE RESEARCH*, 52(1), 651–665. <https://doi.org/10.1080/15230430.2020.1845919>

Published Abstract: Extreme abiotic conditions, geographic isolation, and low levels of disturbance have historically provided alpine, Arctic, and Antarctic regions with low input of and relative resistance to the introduction of new species. However, the climate is warming rapidly, concomitant with intense and diversified types of human influence in these cold environments. Consequently, many plant species, both native and nonnative, are now moving or expanding their ranges to higher elevations and latitudes, creating new species interactions and assemblages that challenge biodiversity conservation. Based on our synthesis, many of the same nonnative species invade multiple cold environments, and many more could move up or over from adjoining warmer areas. Transportation networks and the disturbances associated with burgeoning development are responsible for many movements. Prevention and monitoring for nonnative plant species is of paramount importance, and management should be directed toward species that negatively impact ecosystem function or human well-being. Management of native range shifters is more complicated; most movements will be desirable, but some may be locally undesirable. Overall, plant movements into alpine, arctic, and Antarctic areas are going to increase, and

management will need to be adaptive because species movements and assemblages of the past will not reflect those of the future.

Wasowicz, P., Sennikov, A. N., Westergaard, K. B., Spellman, K., Carlson, M., Gillespie, L. J., Saarela, J. M., Seefeldt, S. S., Bennett, B., Bay, C., Ickert-Bond, S., & Vare, H. (2020). Non-native vascular flora of the Arctic: Taxonomic richness, distribution and pathways. *AMBIO*, *49*(3, SI), 693–703. <https://doi.org/10.1007/s13280-019-01296-6>

Published Abstract: We present a comprehensive list of non-native vascular plants known from the Arctic, explore their geographic distribution, analyze the extent of naturalization and invasion among 23 subregions of the Arctic, and examine pathways of introductions. The presence of 341 non-native taxa in the Arctic was confirmed, of which 188 are naturalized in at least one of the 23 regions. A small number of taxa (11) are considered invasive; these plants are known from just three regions. In several Arctic regions there are no naturalized non-native taxa recorded and the majority of Arctic regions have a low number of naturalized taxa. Analyses of the non-native vascular plant flora identified two main biogeographic clusters within the Arctic: American and Asiatic. Among all pathways, seed contamination and transport by vehicles have contributed the most to non-native plant introduction in the Arctic.