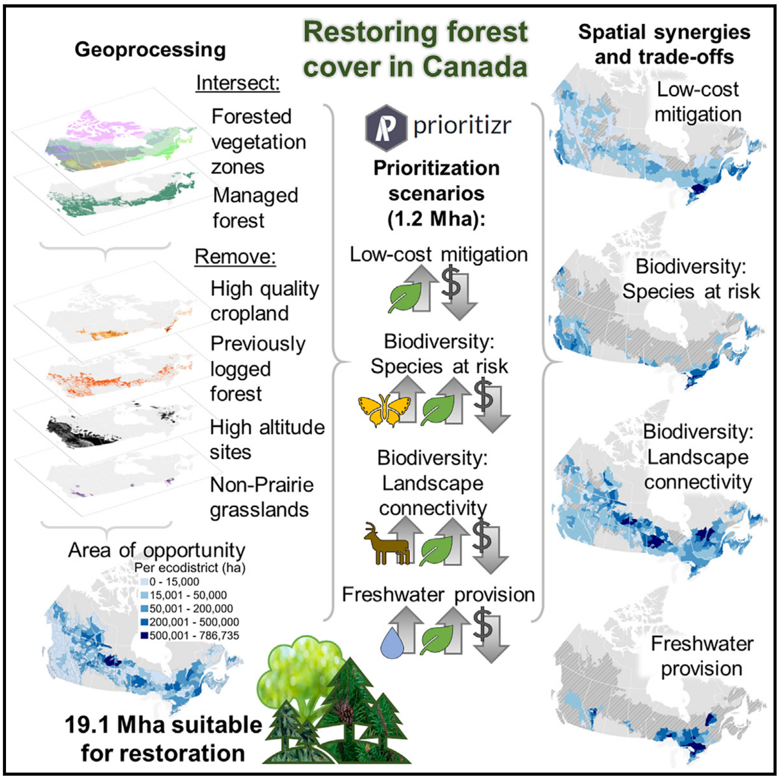
One Earth

Article

Restoring forest cover at diverse sites across Canada can balance synergies and trade-offs

Graphical abstract



Highlights

- Ample area (19.1 Mha) is available for restoration of forest cover in Canada
- Synergies are possible with places that support high biodiversity and tree growth
- Capitalizing on this synergy has a trade-off with economic costs
- Diverse site restoration goals can maximize overall benefit

Authors

C. Ronnie Drever, Alison M. Long, Susan C. Cook-Patton, ..., Richard Schuster, Val Deziel, Zach Xu

Correspondence

cdrever@tnc.org

In brief

Restoring forests can provide cost-effective mitigation of climate change alongside many co-benefits for people and nature. Large-scale policy commitments to restore forests, such as Canada's 2 Billion Trees program, have multiple goals that can be hard to achieve all in the same place. A portfolio approach is most likely to provide the highest collective benefit, with different benefits targeted at different sites. Many areas of high tree growth overlap with high densities of species in peril, indicating an opportunity for restored forests to simultaneously achieve climate and biodiversity goals.

Drever et al., 2025, One Earth *8*, 101177

https://doi.org/10.1016/j.oneear.2025.101177

CellPress

One Earth

CellPress
OPEN ACCESS

Article

Restoring forest cover at diverse sites across Canada can balance synergies and trade-offs

C. Ronnie Drever,[1,11,*] Alison M. Long,[2] Susan C. Cook-Patton,[2] Elizabeth Celanowicz,[3] Joe Fargione,[2] Kathryn Fisher,[4] Steve Hounsell,[3] Werner A. Kurz,[4] Matthew Mitchell,[5] Nathaniel Robinson,[2,6] Richard Pither,[7] Richard Schuster,[8,9] Val Deziel,[3] and Zach Xu[10]

[1]Nature United, 366 Adelaide Street East, Suite 331, Toronto, ON M5A 3X9, Canada
[2]The Nature Conservancy, 4245 North Fairfax Drive, Suite 100, Arlington, VA 22203-1606, USA
[3]Forests Canada, 15 Maple Avenue, Unit 103, Barrie, ON L4N 2N6, Canada
[4]Natural Resources Canada, Pacific Forestry Centre, 506 West Burnside Road, Victoria, BC V8Z 1M5, Canada
[5]Department of Forest Resources Management & Faculty of Land and Food Systems, University of British Columbia, 2329 West Mall, Vancouver, BC V6T 1Z4, Canada
[6]Center for International Forestry Research and World Agroforestry, 221 Old Post Road, Worthington, MA 01098, USA
[7]Environment and Climate Change Canada, 1125 Colonel By Drive, Ottawa, ON K1A 0H3, Canada
[8]Nature Conservancy of Canada, 365 Bloor Street East, Suite 1501, Toronto, ON M4W 3L4, Canada
[9]Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada
[10]Natural Resources Canada, 580 Booth Street, Ottawa, ON K1A 0E4, Canada
[11]Lead contact
*Correspondence: cdrever@tnc.org
https://doi.org/10.1016/j.oneear.2025.101177

SCIENCE FOR SOCIETY While tree planting is a cost-effective strategy to mitigate climate change and biodiversity loss, many initiatives do not fully achieve their potential to deliver benefits for the climate, nature, or people. Poorly planned plantings have led to reduced biodiversity, lost local livelihoods, or short-lived success from inadequate maintenance, drought, or subsequent land clearing. Canada committed to planting 2 billion trees, setting an important global example for large-scale forest restoration. 19.1 million hectares are available where the 2 Billion Trees program could be implemented, which is significantly more than the 1.2 million hectares necessary; thus, significant forethought must be given to select appropriate sites that achieve the program's multiple objectives. Achieving the program's objectives requires balancing synergies between at-risk species' habitat needs and high-tree-growth areas while managing trade-offs like high land costs or limited overlap with areas supporting freshwater provision or nature-based recreation. We mapped restoration scenarios that prioritize different objectives to amplify synergies and characterize solutions to trade-offs. Planting programs with diverse goals need tailored and site-targeted investments to simultaneously and rapidly meet various outcomes.

SUMMARY

Swift action to restore forests is critical for mitigating climate change and preserving biodiversity. Canada has an ambitious program to plant two billion trees to help exceed the country's emissions targets while restoring forest habitat and providing social and economic benefits. We conducted a systematic analysis of where new tree cover can maximally achieve these benefits while minimizing implementation costs. Accounting for critiques of global restoration mapping that include the overestimation of mitigation potential and inadequate biodiversity and social safeguards, we find that 19.1 Mha are available, which is much more than the approximately 1.2 Mha needed to plant two billion trees. Optimization scenarios for 1.2 Mha revealed synergies and trade-offs. Scenarios prioritizing low costs, accessibility, and high growth are concentrated in temperate and coastal areas, overlapping partly with biodiversity scenarios, but with trade-offs of higher costs. A diverse portfolio of regionally restored sites, each tailored for specific attributes, is most likely to deliver multiple benefits at the pace demanded by the current crises.

INTRODUCTION

Tree planting and the restoration of forest cover, alongside decarbonization, are well-recognized nature-based solutions for mitigating climate change.[1] Around the world, companies, non-profit organizations, and governments have initiatives underway to plant trees and restore forests.[2] For instance, the World Economic Forum convened a 10-year effort to conserve or restore forests and grow one trillion trees by 2030,[3] and the Bonn Challenge seeks to restore 350 Mha of forest cover by 2030.[4] Canada is in the top 10 countries with the highest unrealized potential carbon storage on land[5] and so has an important place in realizing the global possibility of forests as a natural climate solution.

The Canadian government has a 2 billion trees (2BT) commitment: a 10-year, $3.16 billion CAD program to plant two billion trees between 2021 and 2031 in collaboration with Indigenous communities, private landowners, cities, provinces, and territories.[6] This program aims to support Canada's emissions reductions goals under the Paris Agreement, with a projected ability to remove up to 12 Tg CO_2e annually by 2050. 2BT also aims to restore biodiversity, with a focus on restoring forest habitat for species at risk (SAR), improving human well-being, and supporting climate-resilient landscapes. While 2BT does not have an explicit area target, two billion trees would fill approximately 1.2 Mha at a typical planting density (1,600 trees/ha).[7]

This desire to achieve multiple goals from one activity is common to many tree planting efforts across the globe,[8] yet not all potential planting areas are equally suited for climate mitigation or offer the same social, cultural, environmental, and economic benefits. Maps of potential planting locations often fail to account for spatial trade-offs. Global maps tend to focus on a few select factors to determine where forest restoration could optimally happen, but these areas may not deliver a multitude of benefits. Geographically refined analyses, in contrast, can incorporate higher-resolution data and a suite of decision-relevant factors to better map the likely feasibility, additionality of climate benefit, and outcomes of forest restoration. Canada provides a unique opportunity to examine how different configurations of restoration implementation can achieve various outcomes, given the known area needed (1.2 Mha) and the ability to evaluate trade-offs across the broader landscape.

While a recent analysis examined carbon and biodiversity benefits of ecological restoration broadly,[9] Canada lacks a systematic analysis showing where additional tree cover can yield optimal climate, human well-being, and biodiversity benefits while minimizing costs or implementation constraints like the distance of project areas to the nearest road.

Here, we demonstrate the potential for achieving multiple objectives from the restoration of forest cover in Canada. We define restoration of forest cover as either active afforestation of lands that were historically forest but converted to other land use or reforestation of forest lands that burned or were otherwise naturally disturbed with little remaining successful tree regeneration. Our definition excludes areas where trees are not naturally dominant, such as native grasslands, shrublands, or arctic tundra. The approach entailed first characterizing the full potential area available for restoration, followed by an assessment of how key attributes of effective forest restoration, such as rates of tree growth, economic costs, accessibility to nearest road, and co-benefits for biodiversity and people, vary across this area of opportunity. We then analyzed scenarios that cover 1.2 Mha within the area of opportunity that each optimize different restoration attributes (Figure 1). We find that a coordinated set of sites, integrated in a portfolio approach whereby each site has different region-specific objectives, is most suitable for most rapidly delivering optimal outcomes for the diversity of social, economic, and ecological goals desired from forest restoration.

RESULTS

Area of opportunity

We identified 19,147,284 ha as the area of opportunity for restoration of forest cover (hereafter, "area of opportunity") (Figure 2). This area is where restoration of forest cover is ecologically appropriate and avoids negative impacts, such as the loss of high-quality agricultural lands (see methods). This estimate represents almost 15-fold more area than the 1.2 Mha called for under 2BT. Currently, land cover in the area of opportunity is 40% shrubland, 39% cropland, and 21% pasture/grassland (see Commission for Environmental Cooperation[10] for definitions of land cover classes and Table S1 for sub-national summaries).

Prioritization scenarios

We examined eight different scenarios that optimized various goals for 2BT (Figure 1). All scenarios sought to optimize climate mitigation potential given that is a primary goal of 2BT. Each scenario mapped the optimal 1.2 Mha for achieving that scenario's goal (Figure 3). Some goals showed positive correlations, suggesting potential synergies, but others were negatively correlated, indicating trade-offs (Figure 4). These trade-offs were reflected in the varying proportions of overlap among the regionally differentiated solutions (Table S2).

The "Low-cost accessible mitigation" (Figure 5), "Low-cost mitigation" (Figure S1), and "Accessible mitigation" (Figure S2) scenarios identified similar areas as optimal. Optimal locations were concentrated in road-accessible, high-growth sites throughout rural areas in southern and eastern Maritime Canada and, to a lesser degree, temperate areas in British Columbia (BC). The 1.2 Mha identified in these scenarios could cumulatively sequester 15.2 Tg C (55.7 Tg CO_2e) after 10 years, i.e., an average of 12.7 Mg C/ha (46.6 Mg CO_2e/ha). These scenarios not only had the highest growth rates and lowest average distance to nearest road, they also showed extensive overlap with areas of high SAR richness. However, they had relatively low values for landscape connectivity, freshwater provision, and nature-based recreation (Figure 3). All three scenarios had moderate to high costs, but accessible mitigation had the highest per-ha costs of the three, 42% higher than both low-cost mitigation and low-cost accessible mitigation.

For each scenario, we measured four attributes related to co-benefits of restoration beyond mitigation. For biodiversity, we assessed the occurrence of SAR in restorable areas and landscape connectivity, assuming that restoration can improve both forest habitat quality and animal movement therein. For ecosystem services important to people, we considered the provision of freshwater and nature-based recreation. Watershed

Please cite this article in press as: Drever et al., Restoring forest cover at diverse sites across Canada can balance synergies and trade-offs, One Earth (2025), https://doi.org/10.1016/j.oneear.2025.101177

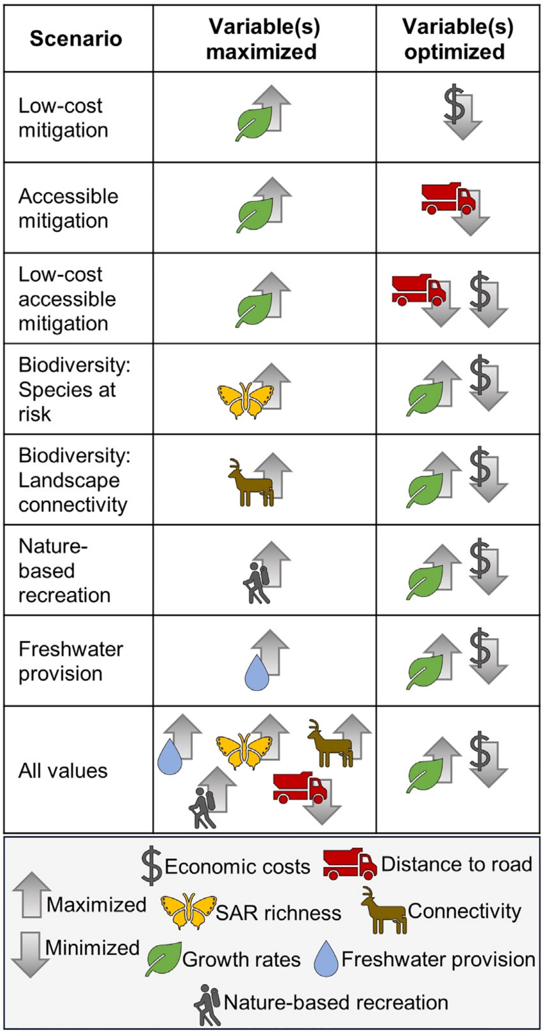


Figure 1. Scenario names and component variables for the restoration of 1.2 Mha of forest cover across the 19.1 Mha area of opportunity in Canada

protection for freshwater provision is often a key motivator for forest restoration,[12,13] and restored forests can be more appealing to visitors and improve visual quality objectives relative to disturbed landscapes,[14–16] meaning restoration can play a role in improving the long-term provision of these ecological services.

The "Biodiversity: Species at risk" scenario (Figure 6) exhibited a roughly similar spatial pattern to the three mitigation-focused scenarios. This scenario showed the second highest growth rates, as well as high values for freshwater provision. However, it had the second highest costs, low values for nature-based recreation and landscape connectivity, and moderately far distance to the nearest road (Figure 3).

This pattern contrasted that of the Biodiversity: Landscape connectivity" scenario (Figure 7). This scenario had low costs but also low growth rates, SAR richness, and freshwater provision, alongside the highest average distance to the nearest road of any scenario and only moderate values for nature-based recreation (Figure 3).

The "Freshwater provision" scenario (Figure 8) had the most concentrated solution. In particular, the solution included 117,000 ha in only one ecodistrict in the Manitoulin-Lake Simcoe ecoregion of southern Ontario (ON), the largest area per ecodistrict in any of the solutions. This scenario showed moderate costs, growth rates, SAR richness, distance to the nearest road, and nature-based recreation but low landscape connectivity (Figure 3).

The "Nature-based recreation" scenario (Figure 9) displayed a highly dispersed solution, akin to biodiversity: landscape connectivity, appearing in ecodistricts across the area of opportunity. This solution had the lowest cost of any scenario but also the lowest growth rates, with the lowest collective mitigation potential of the scenarios, 8.4 Tg C after 10 years (7.0 Mg C/ha) (Figure 3). The solution also had the lowest SAR richness, accompanied by moderate freshwater provision and the second highest average distance to a road and landscape connectivity (Figure 3).

The "All values" solution (Figure S3) resembled closely the pattern identified in Biodiversity: Species at risk (Figure 6). It had high costs, growth rates, and freshwater provision but moderate to low values for the rest of the attributes (Figure 3).

Portions of the area of opportunity were never selected in a solution, with parts in the far north of Canada not prioritized in any scenario (Figure 10A). Selection frequency was highest in coastal BC, south central Canada, and the eastern Maritimes. Southern ON emerged as an opportunity in all the scenarios except for Nature-based recreation.

Synergies and trade-offs

No one scenario scored well for all attributes nationally (Figure 3), indicating trade-offs in how these attributes are distributed across the area of opportunity (Figure 4). In general, areas suitable for forest restoration across Canada showed a positive relationship between higher tree growth rates and richness of SAR but also with costs for implementation and foregone economic opportunity. Thus, maximizing carbon sequestration, while it often meant greater inclusion of SAR habitats, also led to higher costs.

Areas important for maximizing nature-based recreation showed significant negative correlations with growth rates, cost, and SAR richness (Figure 4). Stated otherwise, areas with high value for nature-based recreation tended to cost less but have lower growth rates and SAR richness.

Areas with high value for landscape connectivity tended to be, on average, farther from the nearest road, as landscape connectivity increased with distance to the nearest road (Figure 4). Similar to nature-based recreation, landscape connectivity showed a positive but weak relationship with potential growth, cost, and SAR richness, meaning that areas important for landscape connectivity tended to have lower growth rates and richness of SAR but cost less.

Last, freshwater provision showed no significant correlations with any other attribute. Indeed, the solution for Freshwater provision was the most dissimilar to any other scenario.

The capacity of our national scenarios to simultaneously include different co-benefits varied at a sub-national (i.e., provincial or territorial) scale (Figure 10B). For instance, in the Maritime provinces of eastern Canada (Prince Edward Island, New Brunswick [NB], Nova Scotia [NS]), the scenario that maximized low-cost growth at a national scale (Low-cost mitigation) also yielded

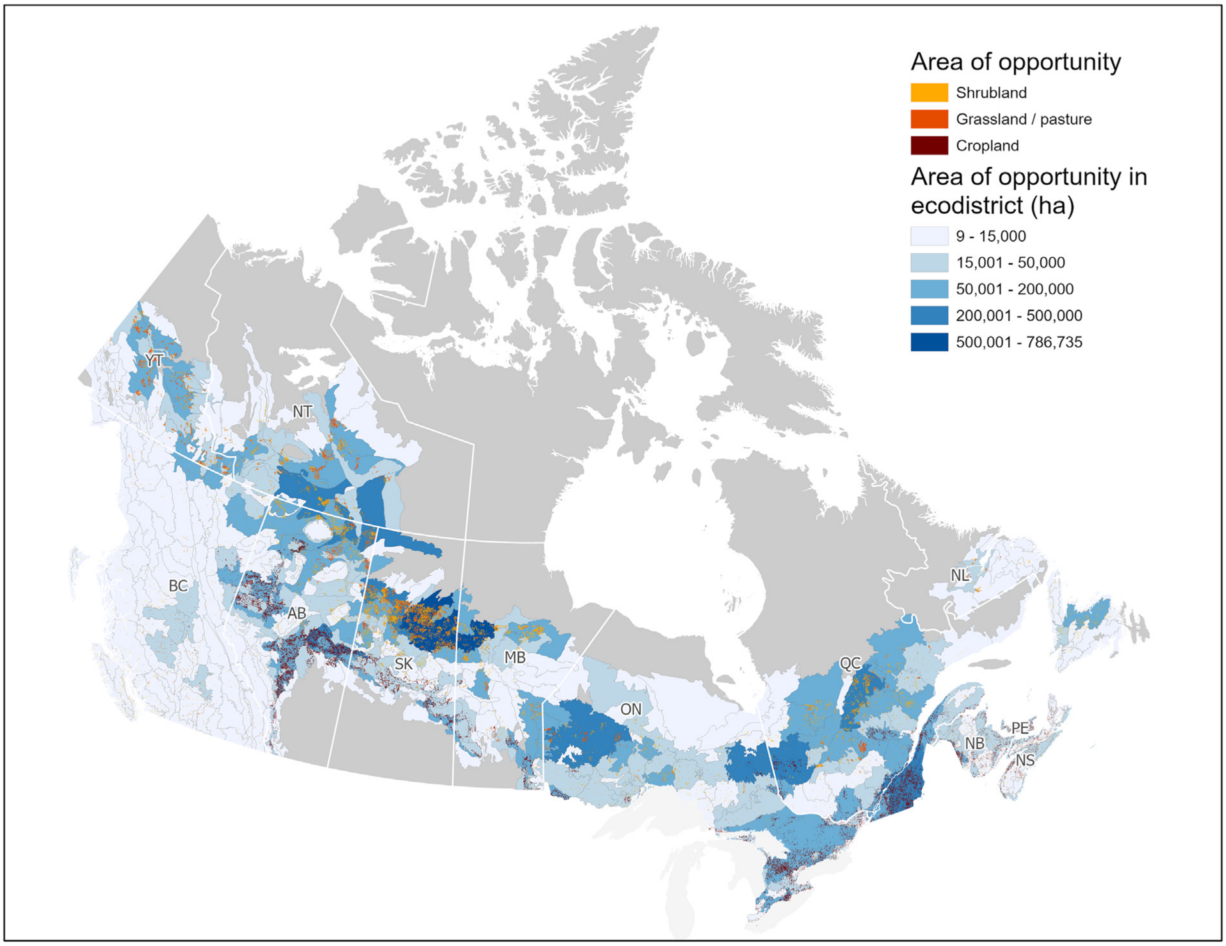


Figure 2. Area of opportunity for the restoration of forest cover in Canada

Each ecodistrict of the National Ecological Framework[11] is color coded by the total area of opportunity contained therein (blue scale). We present results at the ecodistrict scale of the national ecological framework to facilitate their display at a Canada-wide extent. Area of opportunity pixels are shown colored by current land cover class.

the highest co-benefits in terms of the four biodiversity and people variables. Alternatively, the Freshwater provision scenario provided the best outcomes for most variables in ON, whereas in BC, the Biodiversity: Species at risk scenario yielded the highest co-benefits of all scenarios. In other jurisdictions such as Quebec or Alberta (AB), a combination of scenarios was necessary to maximally cover the fulsome set of co-benefits, suggesting important trade-offs at a sub-national scale that may not be present nationally.

DISCUSSION

Ample and globally important opportunity for forest restoration

Our results showed that ample area exists in Canada to realize the 2BT land requirement. We identified 19.1 Mha that meet the programmatic criteria for restoration (Figure 2), an area five times larger than a previous estimate (3.8 Mha) for forest restoration in Canada[17] and fifteen times larger than needed for 2BT.

Our 19.1 Mha estimate represents a sizable fraction (10%) of the area available globally for restoration of forest cover (195 Mha), based on a recent analysis that addresses the principal critiques of overestimation leveled against global reforestation mapping.[18] Reassuringly, our 19.1 Mha estimate is nearly identical to the Canada-specific portion from this study, which includes conservative modeling choices, safeguards for perverse outcomes for people and climate, and high-resolution data.[18] That said, while 19.1 Mha is indeed a large area, the opportunity for effective restoration of forest cover is substantially smaller when considering its capacity to deliver multiple objectives simultaneously.

Based on its composition, the restoration of forest cover in the area of opportunity could take a variety of approaches, including tree planting in southern croplands and non-prairie pastures[19] or reforestation and silviculture in early successional forest areas of Canada's north that currently map as shrublands and grasslands.[20]

Many co-benefits possible but not all simultaneously

Importantly, our results showed that restoration of forest cover can provide important co-benefits for nature and people. If appropriately planned and implemented, then forest restoration

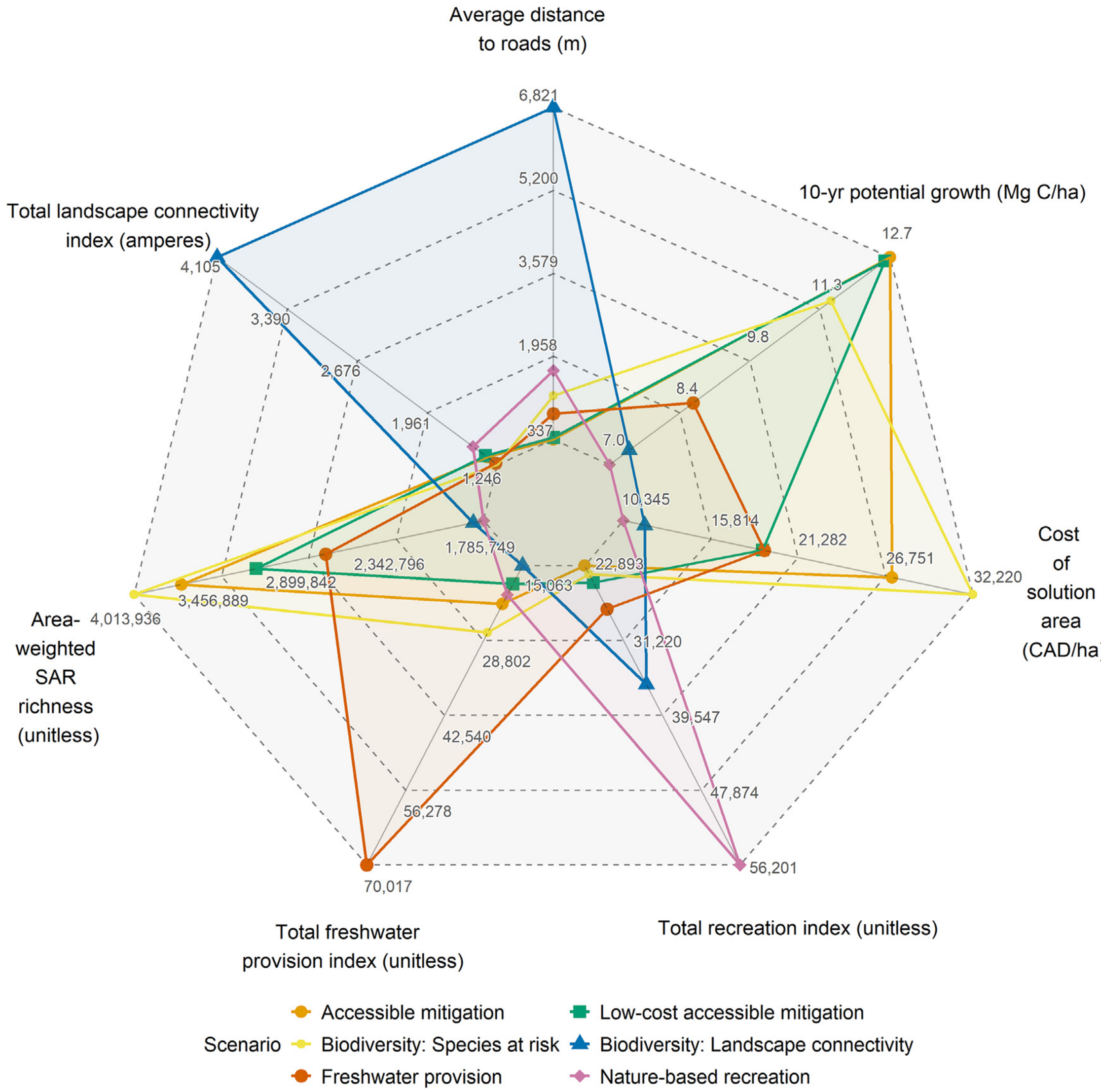


Figure 3. Results of an evaluation framework for eight scenarios of restoration of forest cover in Canada

Each scenario is depicted as a starplot with axes corresponding to the seven variables of restoration interest (see Table S4). Dotted lines indicate data minima, maxima, and quartiles for data distribution of each variable across the different scenarios, e.g., area-weighted SAR richness has the maximum value of all scenarios in the Biodiversity: Species at risk scenario and the lowest in Nature-based recreation. Two scenarios (All values and Low-cost mitigation) are not shown because values for the variables of interest are the same as or nearly identical to other scenarios; the starplot for All values resembled Biodiversity: Species at risk, while Low-cost mitigation resembled Low-cost accessible mitigation.

in scenario-identified parts of the area of opportunity could benefit up to 60 species facing extinction or sequester up to 15.2 Tg C (55.8 Tg CO_2e) after 10 years of growth—a promising potential for meeting the mitigation goal for the 2BT program. However, not all these co-benefits are possible simultaneously, and several spatial synergies and trade-offs are at play. This finding means that decision-makers will be well served by designing a portfolio approach to implementing 2BT, i.e., where multiple sites are chosen for restoration, each with different objectives for co-benefits and that collectively achieve the fulsome set of co-benefits. A portfolio approach allows decision-makers to select alternative sites if the initially targeted sites are not available for restoration. In other words, if a particular site must be dropped from the portfolio, then selecting a substitute can be informed by the objectives achieved by the site that will be replaced, thereby avoiding the risk that alternative sites do not contribute to the overall portfolio.

Our results highlighted the strong synergy between mitigation potential and the conservation of biodiversity. For instance, we observed the highest growth rates in the Mixedwood Plains ecozone of southern ON, which is among the most biodiverse regions in Canada while facing the highest conservation threats and having the least amount of protection.[21] In addition, spatially overlapping solutions from the Low-cost accessible mitigation (Figure 5) and Biodiversity: Landscape connectivity (Figure 7) scenarios overlap with several priority areas in the Staying

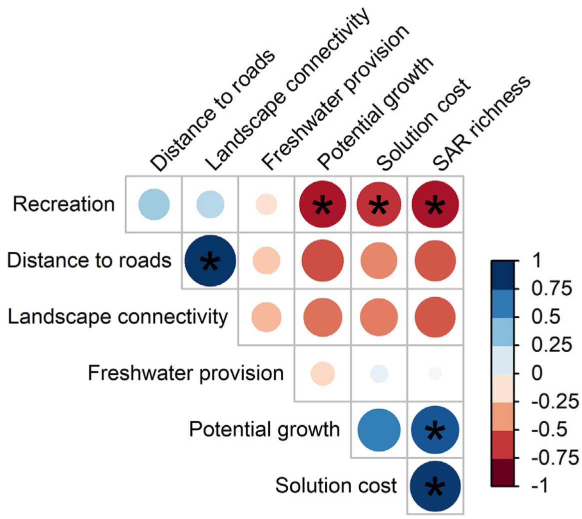


Figure 4. Pearson's correlation matrix among variables in optimization scenarios for the restoration of forest cover in Canada
Circle size and color shade indicate the strength of the correlation between variables. Blue shades (positive coefficients) denote a positive correlation, while red shades (negative coefficients) denote a negative correlation. Asterisks indicate a significant correlation ($p \leq 0.05$).

Connected Initiative.[22] This initiative seeks to enhance transnational ecological connectivity between the USA and Canada.

However, growth rates are highly variable across Canada, and, as illustrated in the scenario results, synergy between mitigation potential and biodiversity conservation was not uniform across the area of opportunity. This situation does not preclude restoration in areas of low forest growth but rather changes its primary driver, e.g., tree planting in disturbed northern areas can restore biodiversity elements, such as habitat for threatened woodland caribou,[23] but mitigation potential would then be a secondary objective.

Similarly, places that simultaneously optimize mitigation potential and biodiversity conservation showed a trade-off with planting costs and foregone economic opportunity (as estimated by agricultural land values) (Figure 3). This trade-off warrants consideration in designing regional strategies for the 2BT implementation, for instance by adjusting tree planting targets and budget allocations in high-cost regions such as southern ON. It also highlights the value of high-growth areas with relatively low land values, such as in eastern NB or central NS, for meeting 2BT goals.[24]

We found that scale influences how restoration can efficiently encompass multiple co-benefits, as we observed different patterns of how co-benefits overlap at national versus sub-national scales (Figure 10B). This scale dependence has been documented globally[25] and underscores the need to consider sub-national patterns of how co-benefits overlap. Decision-makers should develop tailored, regional-scale strategies to achieve co-benefits based on a portfolio approach and thereby increase the prospects of yielding the highest co-benefits from a national investment in forest restoration.

Our findings suggest that an exclusive focus on drinking water provision could compromise the optimization of co-benefits realizable from forest restoration at a national scale. Similar to results from Mitchell et al.,[26] prioritizing actions, either conservation or restoration, based on goals related to freshwater provision leads to solutions quite distinct from other priorities. This is likely a consequence of water provision being driven strongly by downstream demand from agriculture and population centers, drivers of distribution that differ from the other attributes considered here. However, this pattern is not nationally consistent—in jurisdictions where hotspots of freshwater provision occur, such as ON or AB, the restoration of forest areas with high value for freshwater provision can deliver high co-benefits for biodiversity and nature-based recreation (Figure 10B). In any case, the criticality of drinking water and water availability as an ecosystem service is likely to increase as climate change impacts hydrology and water quality.[27,28] Despite its unique drivers, considering the role of forest restoration for water provision will undoubtedly remain important in light of climate change.

Consider who lives in areas identified as restoration priorities

To enhance the chance of long-term success while avoiding risks related to environment injustice, food insecurity, and impacts on marginalized peoples or cultural practices, practitioners should consider three cautionary questions to decide how to allocate restoration efforts: who lives in the places identified as priorities, who pays for the restoration, and who decides on the priorities.[29,30] Many of the areas prioritized in our scenarios are private croplands held by rural farmers, a population that has declined 62% since 1971.[31] In other cases, identified priority areas are early successional forests in public lands and traditional territories of Indigenous peoples. 2BT is a voluntary program and includes a specific funding stream for Indigenous-led projects, meaning the process for deciding where restoration will occur includes self-selection for landowners and stewards who prefer forest restoration over other land uses. That said, the program covers implementation costs but not long-term payments for foregone opportunity costs or the ecological services provided by new forest cover in rural and Indigenous lands.[32] Under the appropriate conditions, payments for ecosystem services have yielded improvements in forest cover while providing rural revenue streams.[33] Expanding the eligibility for these costs could incentivize engagement and alleviate early difficulties of the 2BT program in meeting its planting and mitigation targets.[34] Such an eligibility expansion could divert funds from tree planting itself and risk missing the 2BT target, meaning additional funding may be required.

Site and species selection can increase the durability of new forest cover

Ultimately, realizing the multiple benefits described here requires a long-term perspective, with a focus on the durability of the restoration intervention. While our study did not examine durability risks, they can be mitigated by site selection and planting practices. The selection of project sites should favor regions in the area of opportunity with low or decreasing risk of wildland fire, both historically[35] and projected into the future,[36] such as the eastern temperate forests of ON and QC or the Maritime provinces. Tree plantings and accompanying silvicultural treatments should favor high-diversity species mixes, as these are more resilient to disturbances like wildland fire or drought[37,38]

Please cite this article in press as: Drever et al., Restoring forest cover at diverse sites across Canada can balance synergies and trade-offs, One Earth (2025), https://doi.org/10.1016/j.oneear.2025.101177

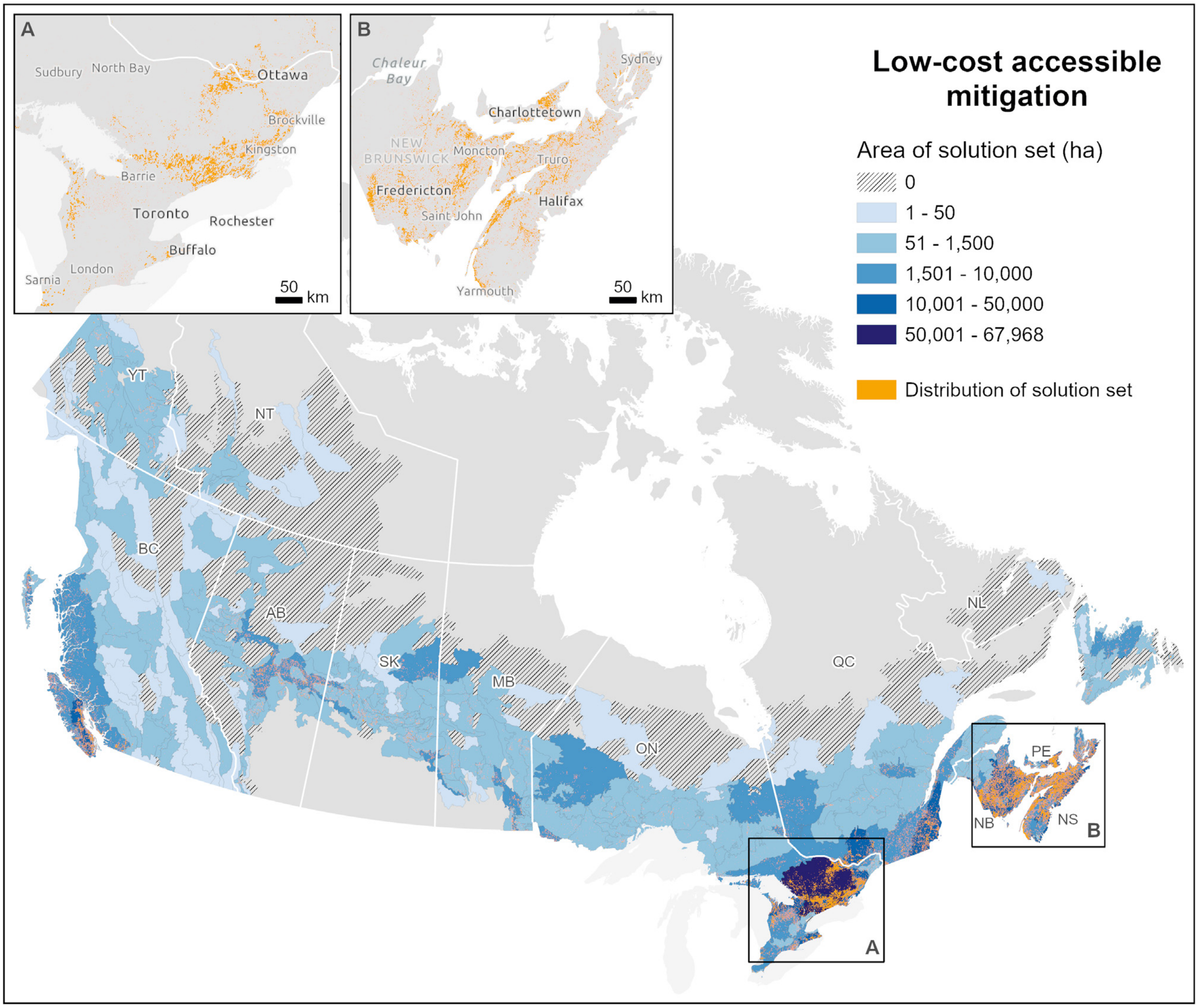


Figure 5. Distribution and area of solution for the Low-cost accessible mitigation scenario for the restoration of forest cover

Each ecodistrict of the National Ecological Framework is color coded by the total solution area therein (blue scale). Area of opportunity pixels for the solution are shown in orange. (A and B) Inset maps show regional details of the area of solution.

and accumulate more carbon than low-diversity plantings or monocultures.[39,40] In areas where fire risk is high or increasing as climate changes, the restoration of forest cover should favor native broadleaf species since wildland fire shows avoidance of deciduous trees and stands.[41]

Fully account for climate dynamics beyond carbon sequestration

Meeting the climate goal of the 2BT program will require planting in areas with high mitigation potential. The growth rates we estimated for the area of opportunity align broadly with spatial patterns of the dynamics of aboveground biomass in Canada,[42] with high biomass accrual in temperate areas and the Pacific and Atlantic maritime areas, with additional hot spots in southern portions of Boreal ecosystems. Nonetheless, our growth estimates are based on natural forest regrowth, meaning it may be possible to get higher aboveground carbon accumulation than estimated in our study by planting and tending trees rather than favoring passive restoration.[43]

Our findings did not account for albedo change from land cover transitions. Since new forests are generally darker than the land cover they replace, this transition tends to decrease albedo and influence atmospheric composition, potentially offsetting the climate benefit of carbon storage.[44–46] This phenomenon is especially true in high-latitude or snow-dominated landscapes like the Boreal region.[47] Such an albedo offset on mitigation potential can be minimized by lowering the prioritization of land cover transitions with large albedo changes (e.g., cropland to conifer forest), preferentially planting in southern and temperate parts of the area of the opportunity where albedo changes are relatively low, or choosing species mixes dominated by lighter-colored deciduous trees.[44,48] Nevertheless, most of the areas

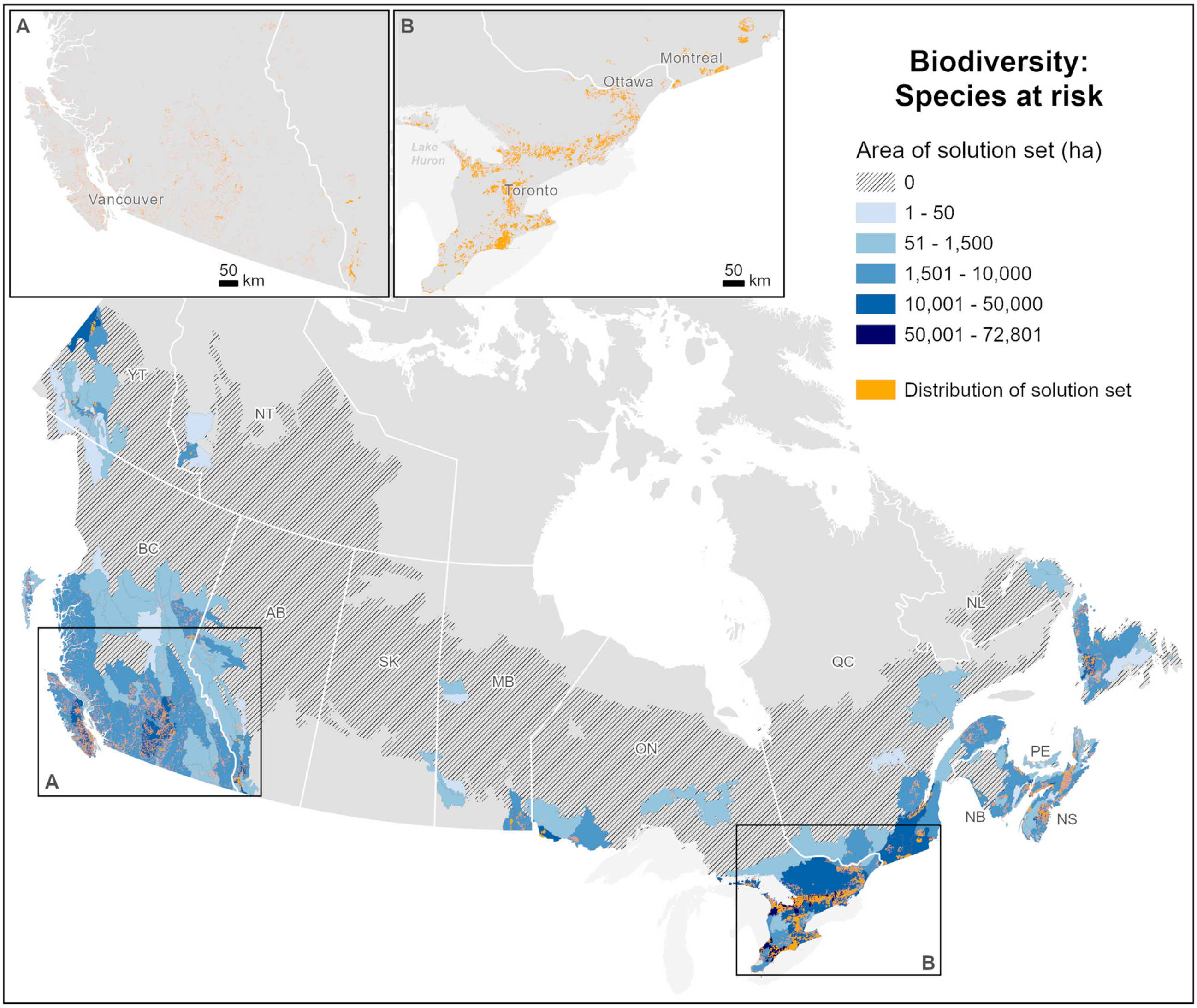


Figure 6. Distribution and area of solution for the Biodiversity: Species at risk scenario for the restoration of forest cover
Each ecodistrict of the National Ecological Framework is color coded by the total solution area therein (blue scale). Area of opportunity pixels for the solution are shown in orange. (A and B) Inset maps show regional details of the area of solution.

in southern and coastal Canada identified by optimization scenarios occur where forest restoration is climate positive even after accounting for the albedo offset.[45]

Include local benefits and constraints

In large part, the net carbon benefit for a given planting project depends on site-level factors, such as the history of site disturbance, soil carbon disturbed during planting, or the silvicultural treatment of existing on-site vegetation.[49,50] This site dependence means that even high-growth sites such as those identified in the Low-cost accessible mitigation scenario may not show a short-term climate benefit from planting. Monitoring carbon dynamics should ideally be part of typical post-planting assessments of survival and "refill" plantings.

The above stresses the importance of tailoring site-level prescriptions to optimize the restoration benefits possible from a given site. This tailoring can support human well-being, for example, by incorporating local and Indigenous knowledge to enhance forest recovery[51] and avoid negative impacts on medicinal plants or non-timber forest products. It also includes capitalizing on existing advanced natural regeneration to reduce project costs and achieve desired stocking,[52] as well as optimizing carbon capture and biodiversity by favoring locally adapted species and provenances.

Consideration of local constraints may reveal limitations to forest restoration not captured in this analysis. For instance, demand for seedlings and labor associated with tree planting can exceed regional supply, as has been documented in the USA.[53] The expansion of supply for seedlings of the “right trees” to plant in the regionally appropriate “right place” may be necessary to meet the 2BT target. Local conditions will strongly affect the full costs required for tree planting to achieve

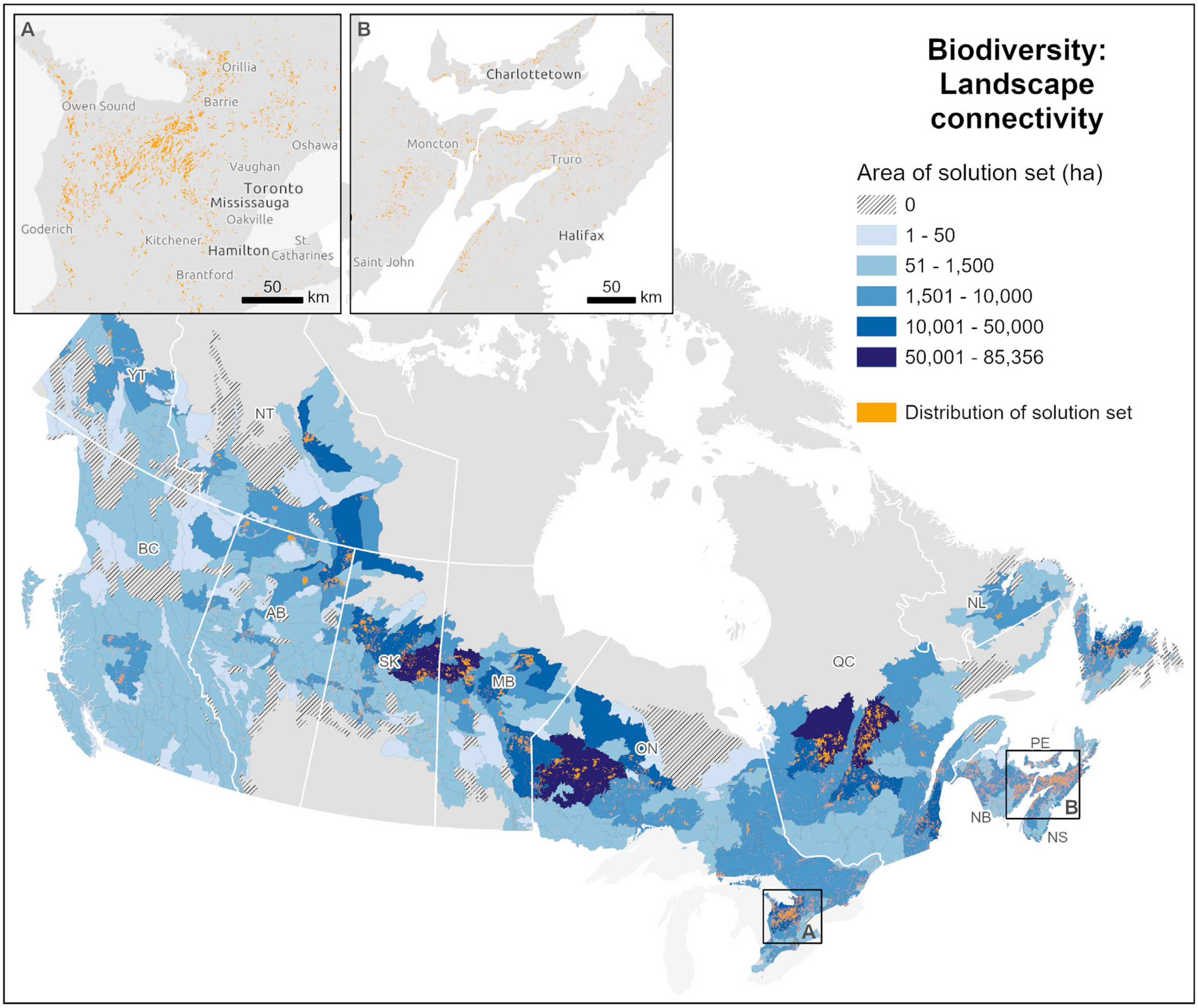


Figure 7. Distribution and area of solution for the Biodiversity: Landscape connectivity scenario for the restoration of forest cover
Each ecodistrict of the National Ecological Framework is color coded by the total solution area therein (blue scale). Area of opportunity pixels for the solution are shown in orange. (A and B) Inset maps show regional details of the area of solution.

the desired change in mitigation potential, recreation value, and other attributes of restoration interest. These costs vary by location, stock type and species, and planting delivery costs. Programmatic spending should cover costs not included in our analyses, such as survival assessments carried out typically at years 2 and 5, as well as refill plantings and the costs of future tending and management decades after the planting (e.g., 20 or 40 years).

Scenario limitations

Our approach to optimization means the results are dependent on the particular metrics we used to prioritize the attributes of interest, although we are encouraged by the amount of overlap identified across these in this analysis. We also acknowledge that our approach focused on where to invest in restoration but not on the expected change to our attributes of interest from restoration. Ideally, our analysis would estimate the impact of new forest on these attributes. For example, it would be instructive to estimate how much landscape connectivity could improve as a result of tree planting in the solution area and, thereby, influence the risk of wildland fire by connecting two previously separated forests. In any case, this national-scale analysis is a first step to help inform the strategic direction of the 2BT program in its early stages. Additional analyses specific to programmatic outcomes are needed, especially at finer spatial scales, to ensure the program can meet its multiple goals.

The need to measure impact is particularly relevant for human well-being, which has multiple facets beyond nature-based recreation and freshwater provision.[54] Improving forest cover may not necessarily yield positive outcomes for human well-being without locally tailored interventions. For instance, restoring an area considered attractive for recreation may not

Please cite this article in press as: Drever et al., Restoring forest cover at diverse sites across Canada can balance synergies and trade-offs, One Earth (2025), https://doi.org/10.1016/j.oneear.2025.101177

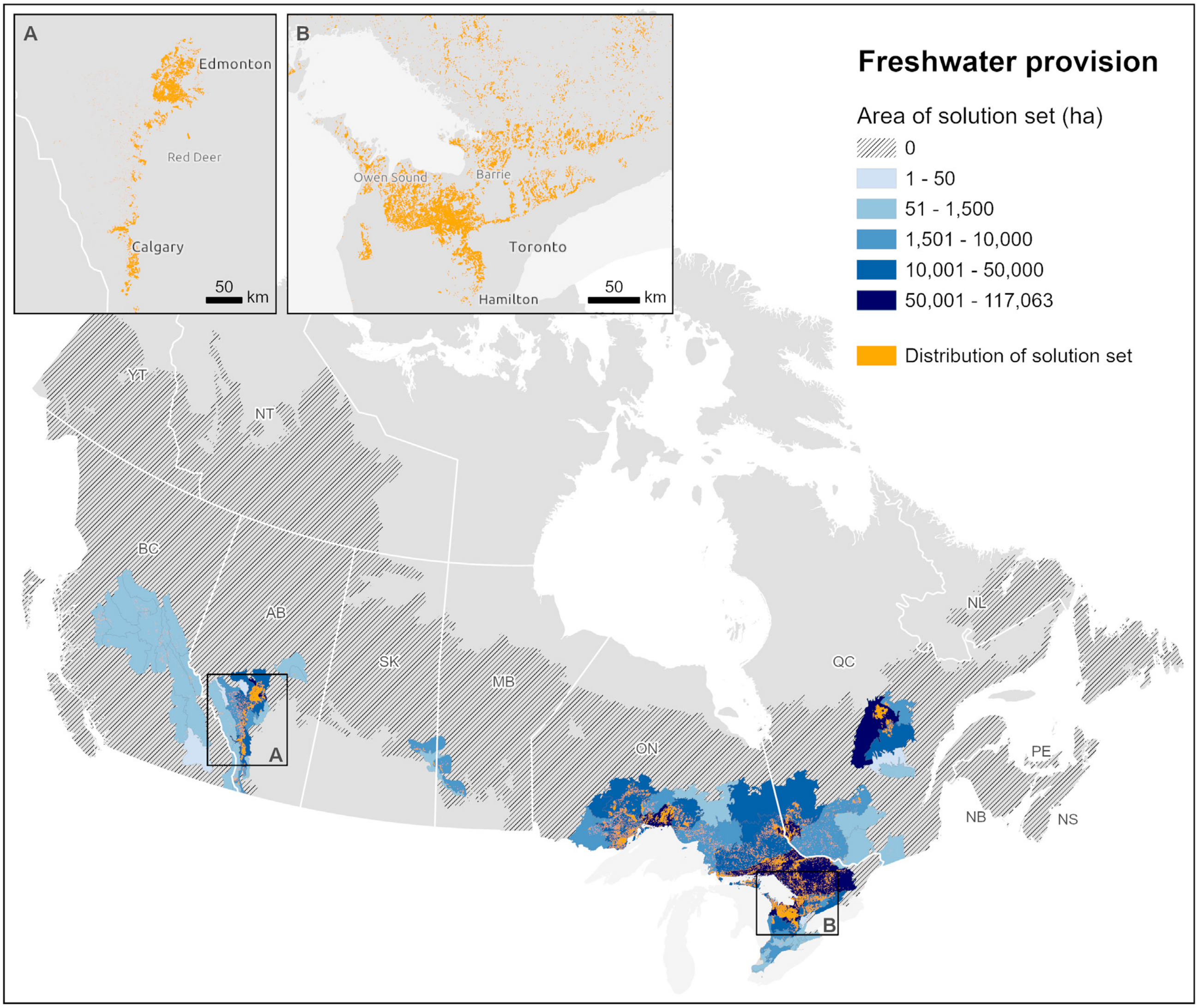


Figure 8. Distribution and area of solution for the Freshwater provision scenario for the restoration of forest cover

Each ecodistrict of the National Ecological Framework is color coded by the total solution area therein (blue scale). Area of opportunity pixels for the solution are shown in orange. (A and B) Inset maps show regional details of the area of solution.

influence visitation if it lacks infrastructure for visitors. For decision makers contemplating support for forest restoration with the goal to improve human well-being, success will likely hinge on the close involvement of potentially affected people in project design, implementation, governance, and measurement of impact.[55,56]

Although we focus on the potential for the mitigation of climate change by restoration of forest cover, these actions are not a substitute for reductions in fossil fuel use.[57] However, even with sharp reductions in fossil fuels, constraining peak warming will require an increase in atmospheric carbon removals.[58] Restoration of forest cover remains one of the most scalable and cost-effective opportunities to remove carbon from the atmosphere.[59] Using Canada as an example, our work shows how to achieve that potential while spatially optimizing the many other benefits desired from new forests.

METHODS

Mapping the area of opportunity for restoration of forest cover

We first identified areas that can naturally support forests using 12 forested zones from the vegetation zones of Canada.[60] Our analysis excluded areas in prairie-dominated biomes because these plantings are often not successful[61] and can reduce biodiversity and ecosystem integrity.[62] This exclusion also avoids the high albedo impacts of a grassland-to-forest transition, as tree cover often absorbs more solar radiation than other land covers and can contribute to climate warming.[45] We focused on areas where closed-canopy forests are naturally dominant to avoid open aspen woodlands, riparian steppe areas, and other low-density treed or arid forest areas; their inclusion in area of opportunity mapping can overestimate restoration potential or create

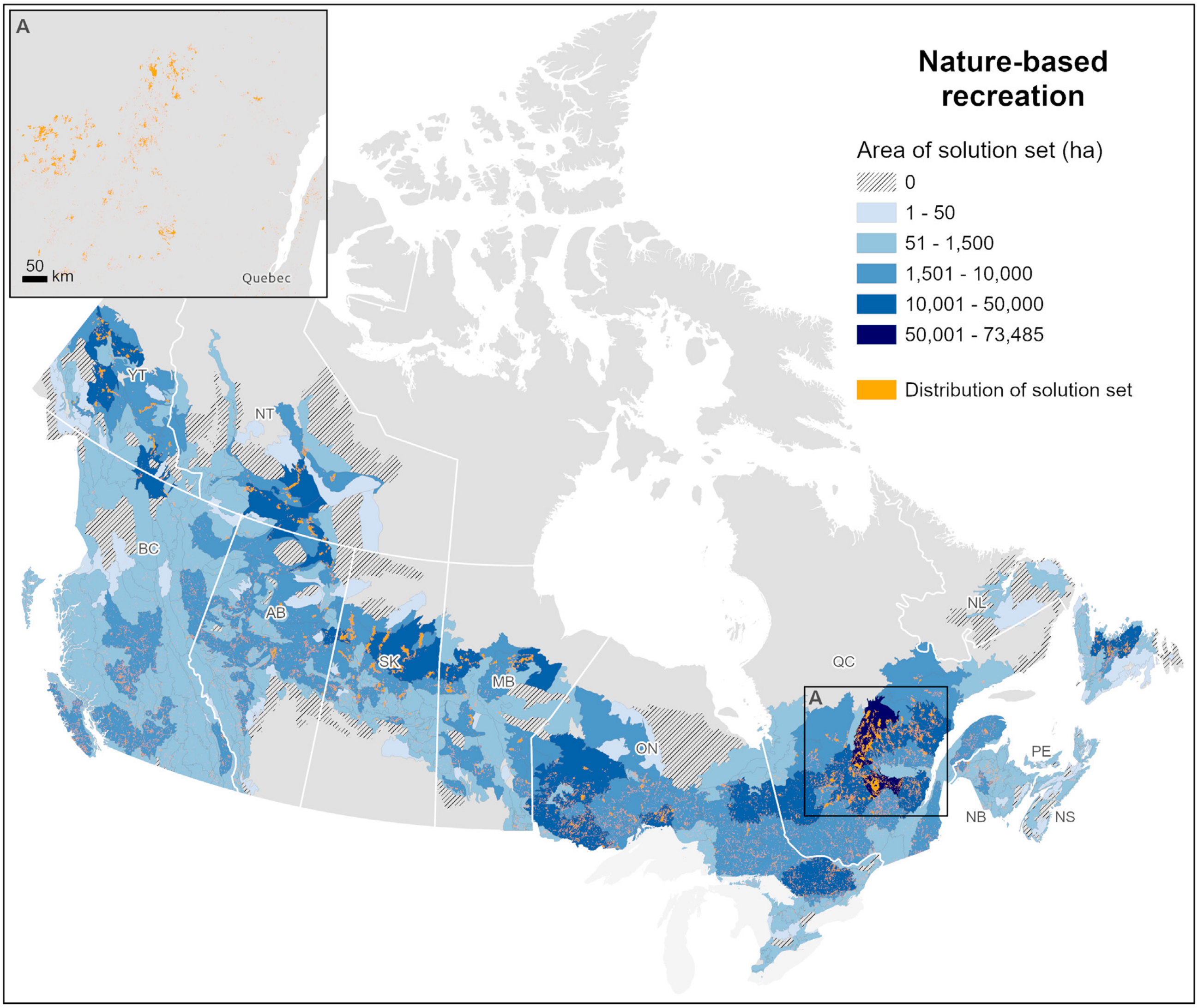


Figure 9. Distribution and area of solution for the Nature-based recreation scenario for the restoration of forest cover
Each ecodistrict of the National Ecological Framework is color coded by the total solution area therein (blue scale). Area of opportunity pixels for the solution are shown in orange. (A) Inset map show regional details of the area of solution.

unintended negative risks for hydrology, carbon storage, biodiversity, or equity dimensions such as pastoral livelihoods.[63,64]

From this area, we removed all areas outside Canada's managed forest as identified in the national inventory report.[65] These areas are remote, often difficult to plant, with slow growth and limited mitigation potential, and have low albedo relative to snow cover (and therefore a reduced mitigation potential due to albedo-related local warming).[17] Next, to avoid conflicts with food security, we removed all areas in Canada's agricultural land cover[66] classified as Canada Land Inventory (CLI) class 1–3 lands, using the CLI mapping (1:250,000 land capability for agriculture). We retained cropland area with severe limitations on productivity (e.g., limited by stoniness, adverse soil, topography, or other factors), defined as CLI class 4–8 or Organic. Due to data gaps in the land capability maps for BC, we further excluded any opportunities for the restoration of forest cover within BC's Agricultural Land Reserve[67] under the assumption that this practice is unfeasible in these protected agricultural lands (some of which are already forested).

We then used this layer to extract a 30-m-resolution raster based on the 2015 North American Land Change Monitoring System (NALCMS) land cover map,[10] with areas not compatible with the restoration of forest cover removed, i.e., all pixels classified as urban, water, or snow and ice. Next, we excluded all pixels classed as forest cover based on the rationale that regeneration efforts in these areas would not be "additional" to the *status quo* in terms of existing legal obligations to regenerate them after logging or contribute to the expansion of new forest cover (i.e., reforestation of existing forest rather than forest reestablishment where forests previously occurred). Moreover, the exclusion of areas that currently map as forest avoids the erroneous inclusion of areas that already have sufficient

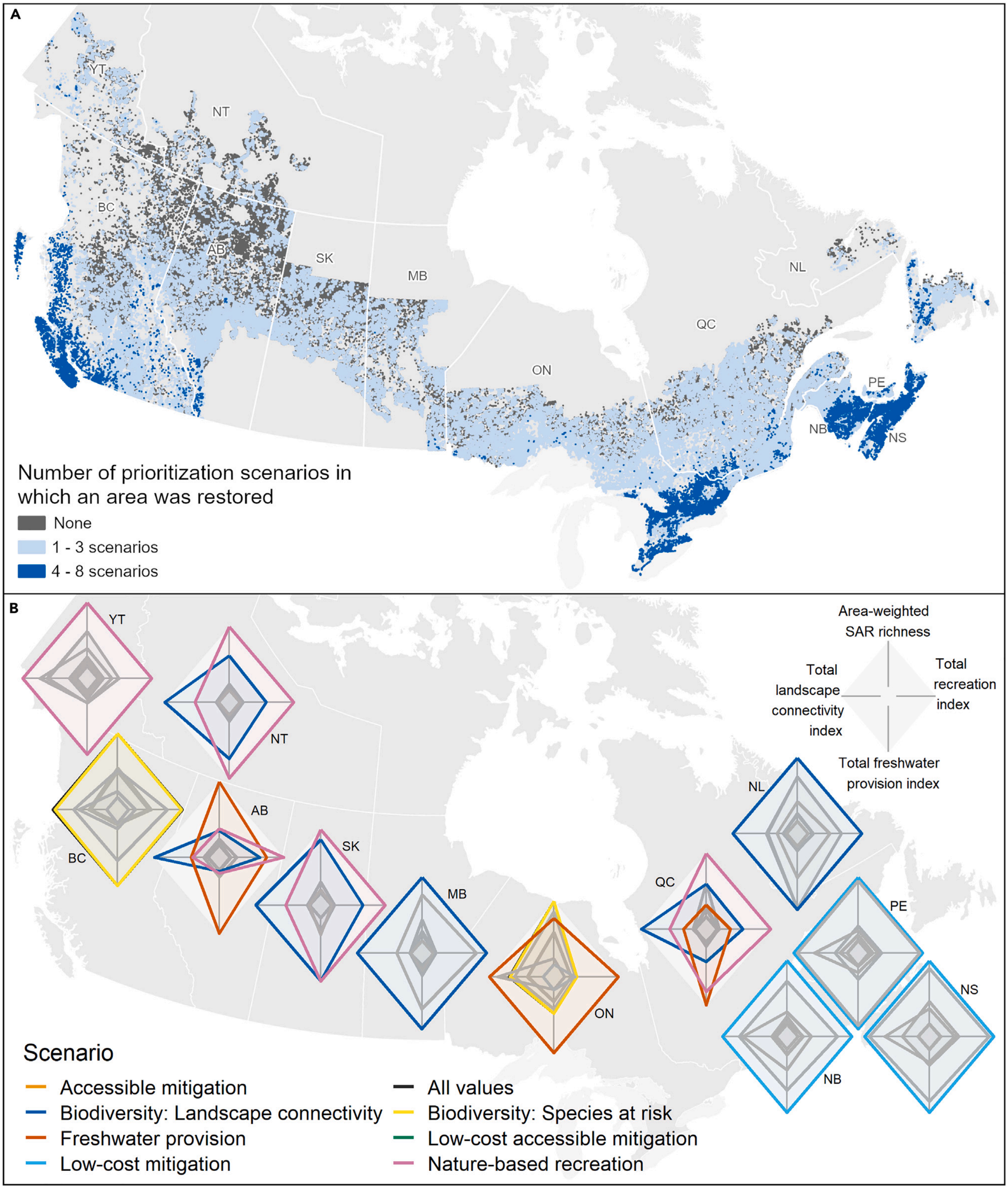


Figure 10. Focal areas for the restoration of forest cover and regional-scale coverage of co-benefits

(A) Priority areas identified in eight optimization scenarios for the restoration of forest cover and (B) depictions of biodiversity and people co-benefits at a provincial or territorial extent. Data in (A) are not to scale; features were enlarged for ease of visual presentation at a national extent. Each starplot in (B) depicts the provincial or territorial portion of scenario solutions assessed at a national scale. Starplot axes correspond to variables of restoration interest related to biodiversity (SAR, ecological connectivity) and people (freshwater provision, nature-based recreation) (see Table S4 for details of the evaluation framework). Scenarios shown in color represent the scenarios that, together, achieve the maximum value for all four co-benefits.

trees, a common data error of global mapping efforts for forest restoration.[18,63]

We further removed all pixels at elevations higher than or equal to 600 m above sea level based on a 30-m digital elevation model,[68] under the rationale these areas have naturally poor growing conditions for trees and, therefore, are not optimal for the restoration of forest cover focused on climate mitigation.

To avoid tree planting in native grasslands where these exist outside of the Canadian Prairies, we removed all areas mapped as native grassland using the annual crop inventory in ON (6,949 ha)[69] and grassland ecosystem mapping in BC (602,343 ha).[70]

These land cover data were then re-sampled to a 300-m resolution for computational efficiency in subsequent analyses, with the land cover class being assigned to the 300-m pixel based on the dominant land cover in component 30-m pixels. We eliminated any grassland or shrubland pixels that did not intersect areas with previous logging or forest fires that occurred between 1984 and 2015,[71] under the rationale that these areas are naturally grassy or shrubby due to edaphic conditions and not suitable for tree cover expansion.

These analyses yielded a total area of opportunity for the restoration of forest cover in Canada (area of opportunity) of 19,147,284 ha (Figure 2). Within this area, the 2BT program applies to both private and public lands and excludes projects where organizations have existing legal obligations to regenerate forests, as these plantings are not considered additional.

All above analyses were carried out in ArcGIS Pro 3.1.[72]

Attribution of area of opportunity with variables of interest

We attributed each pixel in the area of opportunity with data related to growth rates of natural regeneration, biodiversity, benefits for people, and economic costs. In all cases, we extracted the input datasets using masks to obtain rasters that matched our area of opportunity raster in cell size, cell alignment, and spatial extent.

Growth rates of regeneration

To characterize growth rates of regenerating trees in the area of opportunity, we revised a methodology for modeling aboveground carbon accumulation for natural forest regrowth.[12] This approach utilized random forest modeling to predict annual aboveground carbon accumulation at a 1-km resolution based on a suite of environmental and climatic covariates, such as aspect, elevation, annual mean moisture, or precipitation seasonality. Data were tailored for Canada by including additional growth and yield information for a total of 5,362 field plots across Canada, all between 10 and 40 years of age. The root-mean-square error for the model predictions was 0.73, and r^2 was 0.52. These data were then aligned and masked to the 300-m area of opportunity raster.

Biodiversity: SAR and landscape connectivity

We characterized areas with important value for biodiversity using data about two aspects of biodiversity relevant for expansion of forest cover: SAR richness and landscape connectivity. We assumed that forest restoration can improve habitat quality for SAR through tree species choices that are appropriate for the habitat needs of local fauna and flora. We also assume that restoration can enhance landscape connectivity by creating new treed areas among patches of existing forest.

For SAR, we relied on range data for 484 species considered as special concern, threatened, or endangered based on NatureServe data, recovery strategies, and status reports from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).[73] For species with more than one range polygon, COSEWIC reports were consulted to determine whether the polygons should be merged (*n* = 1) or whether older or less accurate records should be excluded (*n* = 8). Historic records were also excluded (*n* = 20). For each remaining species, we generated a raster of presence/absence based on the range map snapped to the area of opportunity.

For landscape connectivity, we used a pan-Canadian analysis that depicts areas important for ecological connectivity for terrestrial mammals.[74] Based on circuit theory, this analysis estimates "current density" at 300-m resolution. Current density is the probability of an animal moving unimpeded from source to destination anywhere within a landscape, much like an electric current moving through circuits of varying conductance while allowing for multiple paths of least resistance.[75] The analysis[74] used empirical data and expert opinion to produce a resistance layer with land cover types known to impede mammal movement, including anthropogenic features, such as urban centers or roads, and natural features, such as steep slopes or large lakes. Predictions of current density were tested using independent wildlife telemetry data, which showed that the movements of individual caribou, wolves, moose, and elk that traveled long distances were significantly correlated with areas of high current densities.

While "currents" tend to travel across natural areas, areas of high current density often include disturbed areas,[74] many of which are captured in the area of opportunity identified here. Tree planting in these areas would, therefore, help increase connectivity. For instance, many areas of high current density in southern ON occur along discontinuous wooded areas within agricultural lands, where forest cover restoration to connect these areas could improve connectivity.

Note that areas of high current density do not necessarily correspond to areas of high biodiversity as characterized by species richness. Current density reflects barriers to animal movement, whereas our species-richness data reflect the well-understood latitudinal gradient in biodiversity, such that areas in southern Canada have the highest richness. These southern areas are also subject to the highest levels of human disturbance, meaning remnant natural areas are frequently disconnected from other patches of habitat. In other words, it is often the case in Canada that an inverse relationship exists between species richness and current density.

Benefits for people: Freshwater provision and nature-based recreation

We assessed national-scale data related to two socially important ecosystem services: freshwater provision and nature-based recreation. For freshwater, we used 250-m-resolution data that characterize the provision of freshwater runoff for human use at any given location using information on hydrological connectivity combined with water demand for agricultural, industrial, residential, and hydropower uses.[26] These data assign high values of freshwater provision to upstream areas with high capacity (i.e., high runoff) that are linked to high downstream demand. We assumed that forest restoration in areas important for the provision of freshwater helps filter water and maintain or improve its quality, especially through reductions in soil erosion as well as increased soil infiltration. However, these patterns will depend on climate, soil type, and the species of trees planted, as in some cases, fast-growing trees can actually reduce water yields through higher evapotranspiration compared to other species or mature vegetation.[26]

For nature-based recreation, we relied on data that depict "wilderness" areas[26] and their capacity to provide recreational opportunities based on their naturalness and attractiveness for nature-based recreation, combined with their accessibility and the number of people that could access these areas. Areas with high values for nature-based recreation are road accessible, relatively close to human population centers, near mountains and water bodies, and have high land cover naturalness but low population density. We assumed that the restoration of tree cover in these areas could enhance their value for nature-based recreation since evidence suggests that people value natural landscapes, including forested ones, to a greater degree than human-disturbed lands.[76]

Economic costs

We estimated the economic cost of restoration of forest cover by considering implementation and foregone opportunity costs. Per-ha costs of implementation included site preparation, seedling production, and tree planting and tending. These costs account for differences in flat terrain ($\leq$10% slope) versus steeper slopes (>10%) and tree taxa of planting stock (coniferous, mixed, deciduous). We derived these estimates from Drever et al.[17] and adjusted them to 2020 CAD (Table S3).

We estimated the slope using the surface parameters tool in ArcGIS Pro based on a 30-m digital elevation model[68] snapped to the NALCMS 30-m land cover raster. Planting stock choice for each pixel in the area of opportunity was assigned according to the dominant tree species in intersecting forest regions of Canada.[77] These data were then re-sampled as the average value of component 30-m pixels and snapped to the 300-m raster of area of opportunity.

We estimated the foregone opportunity costs for sites converted to forest from marginal farmland as a proxy for restoration based on this type of land conversion as well as other land uses, given data availability at a nationally consistent extent. Opportunity cost is commonly represented by land rents foregone in perpetuity and forgone option value.[78–81] In this study, we used agricultural land values from the 2021 Census of Agriculture[82] for census consolidated subdivisions (CCSs) (n = 1,428) to represent both the forgone land rents and option values. We calculated these per-ha costs by dividing the total farm capital (the value of land and buildings in owned or rented lands)[83] by the total farm area for each CCS.[84] Since data coverage was not complete for all CCSs, we estimated the opportunity costs for 218 CCSs based on the average of neighboring CCSs using the Fill Missing Values tool in ArcGIS Pro. For 44 CCSs in Prince Edward Island with null data (and no CCSs with contiguous edges), we relied on data on farm capital and area from the census agricultural region, the next higher-level unit of dissemination of agricultural data by Statistics Canada. Since the Statistics Canada data do not distinguish marginal farmland, we acknowledge that the estimated opportunity costs for restoration of forest cover may be overestimated and so should be considered conservative. These polygonal data were sampled and snapped to the area of opportunity and then summed with the raster of implementation costs.

Distance to nearest road

We considered the feasibility of access for planters and machinery by estimating the distance of planting sites to the nearest road. We estimated the distance from the pixel center to the nearest road using a recent comprehensive national layer of vehicle access roads[85] and accounting for land surface elevation changes in the distance estimation. This calculation was first performed on the 30-m land cover raster, re-sampled as the average distance to a road of component pixels, and then snapped to the 300-m raster of area of opportunity.

Prioritization scenarios and evaluation

We analyzed eight prioritization scenarios of forest restoration within the area of opportunity (Figure 1). Prioritization relied on *prioritzr* software,[86] a package in R[87] that uses mixed integer linear programming to solve problems related to conservation planning, along with the exact algorithm solver Gurobi 10.0.1.[88] We compared optimal networks of areas ("solutions") according to scenarios that maximized one variable (e.g., growth rates) based on an area constraint (1.2 Mha) while optimizing others (e.g., solution cost or nearest distance to a road). We evaluated these scenarios at national and jurisdictional scales against a common set of metrics based on the variables of restoration interest (Table S4).

The Low-cost mitigation scenario identified the areas that collectively yield the highest mitigation, i.e., 10-year carbon accumulation (Mg C/ha), at the lowest cost in terms of implementation and foregone economic opportunity (CAD/ha). Accessible mitigation maximized mitigation while minimizing distance to the nearest road (m). Low-cost accessible mitigation characterized a solution with the highest mitigation at the lowest cost and the highest road accessibility. We evaluated four scenarios that maximized different values while optimizing low-cost mitigation: Biodiversity: Species at risk found areas that collectively maximized an area-weighted estimate of richness (unitless index) for SAR of extinction; Biodiversity: Landscape connectivity identified places with high values for connectivity of movements of terrestrial mammals (current density in amperes); Nature-based recreation characterized areas with the highest estimated value for people to recreate in the outdoors (unitless index); and Freshwater provision identified areas that can best support the provision of freshwater for human communities (unitless index). An eighth scenario (All values) identified road-accessible areas that best include the above values while optimizing low-cost mitigation.

We examined relationships among these variables through a correlation matrix using the Pearson coefficient analyzing scenario-specific data for each of the seven variables of interest from our eight scenarios (Figure 4). The correlation analysis was derived by the *cor* function in base R and visualized by the *corrplot_0.92* package in R. We determined statistical significance using the *Hmisc_5.1-1* package (p < 0.05).

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to the lead contact, Dr. C. Ronnie Drever (cdrever@tnc.org).

Please cite this article in press as: Drever et al., Restoring forest cover at diverse sites across Canada can balance synergies and trade-offs, One Earth (2025), https://doi.org/10.1016/j.oneear.2025.101177

CellPress
OPEN ACCESS

Materials availability

All data needed to evaluate the conclusions in the paper are in the paper itself or the supplemental information. An online viewer for the spatial data used in the analysis and scenario results is available at www.natureunited.ca/reforestcan.

Data and code availability

Spatial data for the area of opportunity for forest restoration, input variables, and scenario results can be found at the Harvard Dataverse repository: https://doi.org/10.7910/DVN/5D3SZI. All spatial datasets used in this study are publicly available from the referenced studies with one exception: data for aboveground carbon accumulation were derived from the source study and are available upon request from the lead contact.

ACKNOWLEDGMENTS

Thanks to Monique Dosanjh for assistance in the development of opportunity cost data. This study was made possible by The Nature Conservancy's FinishLine Fund and Bezos Earth Fund. We recognize the in-kind contributions made by the institutions of participating authors and appreciate donors who support acceleration of natural climate solutions.

AUTHOR CONTRIBUTIONS

C.R.D. assembled and coordinated the research team and led the writing/editing. All authors discussed and reviewed several versions of the manuscript and contributed to the design of the analyses and data used. A.M.L. developed the geospatial analyses, maps, and figures. R.S. and A.M.L. coded and ran the prioritizations. N.R. developed the data for aboveground carbon accumulation. Z.X. led the data development of economic costs.

DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2025.101177.

Received: March 15, 2024
Revised: December 16, 2024
Accepted: January 6, 2025
Published: January 14, 2025

REFERENCES

1. de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., Dong, W., Ford, J., Fuss, S., and Hourcade, J.-C. (2018). Strengthening and implementing the global response Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. In the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (Cambridge University Press), pp. 313–444.
2. Sewell, A., Van der Esch, S., and Löwenhardt, H. (2020). Goals and Commitments for the Restoration Decade: A Global Overview of Countries' Restoration Commitments under the Rio Conventions and Other Pledges (PBL Netherlands Environmental Assessment Agency).
3. World Economic Forum (2020). A platform for the trillion trees community. 1t.org. https://www.1t.org/.
4. International Union for Conservation of Nature (2020). The Bonn Challenge | Bonchallenge. https://www.bonnchallenge.org/.
5. Walker, W.S., Gorelik, S.R., Cook-Patton, S.C., Baccini, A., Farina, M.K., Solvik, K.K., Ellis, P.W., Sanderman, J., Houghton, R.A., Leavitt, S.M., et al. (2022). The global potential for increased storage of carbon on land. Proc. Natl. Acad. Sci. USA *119*, e2111312119. https://doi.org/10.1073/pnas.2111312119.
6. Government of Canada (2020). 2 Billion Trees Commitment. https://www.canada.ca/en/campaign/2-billion-trees.html.
7. Magnus, G.K., Celanowicz, E., Voicu, M., Hafer, M., Metsaranta, J.M., Dyk, A., and Kurz, W.A. (2021). Growing our future: Assessing the outcome of afforestation programs in Ontario, Canada. For. Chron. *97*, 179–190. https://doi.org/10.5558/tfc2021-019.
8. Hua, F., Bruijnzeel, L.A., Meli, P., Martin, P.A., Zhang, J., Nakagawa, S., Miao, X., Wang, W., McEvoy, C., Peña-Arancibia, J.L., et al. (2022). The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches. Science *376*, 839–844. https://doi.org/10.1126/science.abl4649.
9. Currie, J., Merritt, W., Liang, C., Sothe, C., Beatty, C.R., Shackelford, N., Hirsh-Pearson, K., Gonsamo, A., and Snider, J. (2023). Prioritizing ecological restoration of converted lands in Canada by spatially integrating organic carbon storage and biodiversity benefits. Conserv. Sci. Pract. *5*, e12924. https://doi.org/10.1111/csp2.12924.
10. Commission for Environmental Cooperation (2020). Land Cover 30m, 2015 (Landsat and RapidEye). Commission for Environmental Cooperation. http://www.cec.org/north-american-environmental-atlas/land-cover-30m-2015-landsat-and-rapideye/.
11. Ecological Stratification Working Group (1996). A national ecological framework for Canada (Centre for Land and Biological Resources Research, State of the Environment Directorate).
12. Cook-Patton, S.C., Leavitt, S.M., Gibbs, D., Harris, N.L., Lister, K., Anderson-Teixeira, K.J., Briggs, R.D., Chazdon, R.L., Crowther, T.W., Ellis, P.W., et al. (2020). Mapping carbon accumulation potential from global natural forest regrowth. Nature *585*, 545–550. https://doi.org/10.1038/s41586-020-2686-x.
13. Keller, A.A., and Fox, J. (2019). Giving credit to reforestation for water quality benefits. PLoS One *14*, e0217756. https://doi.org/10.1371/journal.pone.0217756.
14. Peña, L., Casado-Arzuaga, I., and Onaindia, M. (2015). Mapping recreation supply and demand using an ecological and a social evaluation approach. Ecosyst. Serv. *13*, 108–118. https://doi.org/10.1016/j.ecoser.2014.12.008.
15. Vecchiato, D., Pellizzari, C.B., and Tempesta, T. (2023). Using Choice Experiments as a Planning Tool for Reforestation after Extreme Events: The Case of the Vaia Windstorm in Italy. Forests *14*, 1374. https://doi.org/10.3390/f14071374.
16. Zulian, G., Paracchini, M.L., Maes, J., and Liquete, C. (2013). ESTIMAP: Ecosystem Services Mapping at European Scale (European Commission Joint Research Centre)).
17. Drever, C.R., Cook-Patton, S.C., Akhter, F., Badiou, P.H., Chmura, G.L., Davidson, S.J., Desjardins, R.L., Dyk, A., Fargione, J.E., Fellows, M., et al. (2021). Natural climate solutions for Canada. Sci. Adv. *7*, eabd6034. https://doi.org/10.1126/sciadv.abd6034.
18. Fesenmyer, K., and Cook-Patton, S.C. (2024). Reforestation. Version 1.0. https://app.naturebase.org/data/nb/4https://app.naturebase.org/data/nb/4.
19. Cunningham, S.C., Mac Nally, R., Baker, P.J., Cavagnaro, T.R., Beringer, J., Thomson, J.R., and Thompson, R.M. (2015). Balancing the environmental benefits of reforestation in agricultural regions. Perspect. Plant Ecol. Evol. Systemat. *17*, 301–317. https://doi.org/10.1016/j.ppees.2015.06.001.
20. Cyr, D., Splawinski, T.B., Pascual Puigdevall, J., Valeria, O., Leduc, A., Thiffault, N., Bergeron, Y., and Gauthier, S. (2022). Mitigating post-fire regeneration failure in boreal landscapes with reforestation and variable retention harvesting: At what cost? Can. J. For. Res. *52*, 568–581. https://doi.org/10.1139/cjfr-2021-0180.
21. Kraus, D., and Hebb, A. (2020). Southern Canada's crisis ecoregions: identifying the most significant and threatened places for biodiversity

conservation. Biodivers. Conserv. *29*, 3573–3590. https://doi.org/10.1007/s10531-020-02038-x.

22. Staying Connected Initiative (2022). Key Linkage Areas: Staying Connected Initiative. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/8905860a33fb4118aba55be06a765c8a.
23. Filicetti, A.T., Cody, M., and Nielsen, S.E. (2019). Caribou conservation: restoring trees on seismic lines in Alberta, Canada. Forests *10*, 185.
24. Farm Credit Canada (2022). 2022 FCC Farmland Values Report (Farm Credit Canada).
25. Strassburg, B.B.N., Iribarrem, A., Beyer, H.L., Cordeiro, C.L., Crouzeilles, R., Jakovac, C.C., Braga Junqueira, A., Lacerda, E., Latawiec, A.E., Balmford, A., et al. (2020). Global priority areas for ecosystem restoration. Nature *586*, 724–729. https://doi.org/10.1038/s41586-020-2784-9.
26. Mitchell, M.G.E., Schuster, R., Jacob, A.L., Hanna, D.E.L., Dallaire, C.O., Raudsepp-Hearne, C., Bennett, E.M., Lehner, B., and Chan, K.M.A. (2021). Identifying key ecosystem service providing areas to inform national-scale conservation planning. Environ. Res. Lett. *16*, 014038. https://doi.org/10.1088/1748-9326/abc121.
27. Schindler, D.W., and Donahue, W.F. (2006). An impending water crisis in Canada's western prairie provinces. Proc. Natl. Acad. Sci. USA *103*, 7210–7216. https://doi.org/10.1073/pnas.0601568103.
28. Crossman, J., Futter, M.N., Oni, S.K., Whitehead, P.G., Jin, L., Butterfield, D., Baulch, H.M., and Dillon, P.J. (2013). Impacts of climate change on hydrology and water quality: Future proofing management strategies in the Lake Simcoe watershed, Canada. J. Great. Lakes. Res. *39*, 19–32. https://doi.org/10.1016/j.jglr.2012.11.003.
29. Fleischman, F., Coleman, E., Fischer, H., Kashwan, P., Pfeifer, M., Ramprasad, V., Rodriguez Solorzano, C., and Veldman, J.W. (2022). Restoration prioritization must be informed by marginalized people. Nature *607*, E5–E6. https://doi.org/10.1038/s41586-022-04733-x.
30. Melo, F.P., Mazzochini, G.G., Guidotti, V., and Manhães, A.P. (2023). Using land inequality to inform restoration strategies for the Brazilian dry forest. Landsc. Urban Plann. *239*, 104844. https://doi.org/10.1016/j.landurbplan.2023.104844.
31. Statistics Canada (2023). The socioeconomic snapshot of Canada's evolving farm population, 2021. https://www150.statcan.gc.ca/n1/daily-quotidien/230825/dq230825a-eng.htm.
32. Government of Canada (2023). 2BT Tree planting applicant guide. https://www.canada.ca/en/campaign/2-billion-trees/2-billion-trees-program/2-billion-trees-program-ongoing-call-for-proposals/2bt-tree-planting-application-guide.html.
33. Rijal, S., Techato, K., Gyawali, S., Stork, N., Dangal, M.R., and Sinutok, S. (2021). Forest Cover Change and Ecosystem Services: A Case Study of Community Forest in Mechinagar and Buddhashanti Landscape (MBL), Nepal. Environ. Manage. *67*, 963–973. https://doi.org/10.1007/s00267-021-01430-9.
34. Auditor General of Canada (2023). Report 1—Forests and Climate Change (Office of the Auditor General of Canada).
35. Hanes, C.C., Wang, X., Jain, P., Parisien, M.-A., Little, J.M., and Flannigan, M.D. (2019). Fire-regime changes in Canada over the last half century. Can. J. For. Res. *49*, 256–269. https://doi.org/10.1139/cjfr-2018-0293.
36. Wang, X., Studens, K., Parisien, M.-A., Taylor, S.W., Candau, J.-N., Boulanger, Y., and Flannigan, M.D. (2020). Projected changes in fire size from daily spread potential in Canada over the 21st century. Environ. Res. Lett. *15*, 104048.
37. King, R.A., Pullen, J., Cook-Patton, S.C., and Parker, J.D. (2023). Diversity stabilizes but does not increase sapling survival in a tree diversity experiment. Restor. Ecol. *31*, e13927. https://doi.org/10.1111/rec.13927.
38. Messier, C., Bauhus, J., Sousa-Silva, R., Auge, H., Baeten, L., Barsoum, N., Bruelheide, H., Caldwell, B., Cavender-Bares, J., Dhiedt, E., et al. (2022). For the sake of resilience and multifunctionality, let's diversify planted forests. Conservation Letters *15*, e12829. https://doi.org/10.1111/conl.12829.
39. Hof, A.R., Dymond, C.C., and Mladenoff, D.J. (2017). Climate change mitigation through adaptation: the effectiveness of forest diversification by novel tree planting regimes. Ecosphere *8*, e01981. https://doi.org/10.1002/ecs2.1981.
40. Warner, E., Cook-Patton, S.C., Lewis, O.T., Brown, N., Koricheva, J., Eisenhauer, N., Ferlian, O., Gravel, D., Hall, J.S., and Jactel, H. (2022). Higher aboveground carbon stocks in mixed-species planted forests than monocultures–a meta-analysis. Preprint at bioRxiv. https://doi.org/10.1101/2022.01.17.476441.
41. Bernier, P., Gauthier, S., Jean, P.-O., Manka, F., Boulanger, Y., Beaudoin, A., and Guindon, L. (2016). Mapping local effects of forest properties on fire risk across Canada. Forests *7*, 157.
42. Wulder, M.A., Hermosilla, T., White, J.C., and Coops, N.C. (2020). Biomass status and dynamics over Canada's forests: Disentangling disturbed area from associated aboveground biomass consequences. Environ. Res. Lett. *15*, 094093. https://doi.org/10.1088/1748-9326/ab8b11.
43. Bonner, M.T., Schmidt, S., and Shoo, L.P. (2013). A meta-analytical global comparison of aboveground biomass accumulation between tropical secondary forests and monoculture plantations. For. Ecol. Manag. *291*, 73–86. https://doi.org/10.1016/j.foreco.2012.11.024.
44. Betts, R.A. (2000). Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature *408*, 187–190. https://doi.org/10.1038/35041545.
45. Hasler, N., Williams, C.A., Denney, V.C., Ellis, P.W., Shrestha, S., Terasaki Hart, D.E., Wolff, N.H., Yeo, S., Crowther, T.W., Werden, L.K., and Cook-Patton, S.C. (2024). Accounting for albedo to identify climate positive tree cover restoration. Nat. Commun. *15*, 2275. https://doi.org/10.1038/s41467-024-46577-1.
46. Weber, J., King, J.A., Abraham, N.L., Grosvenor, D.P., Smith, C.J., Shin, Y.M., Lawrence, P., Roe, S., Beerling, D.J., and Martin, M.V. (2024). Chemistry-albedo feedbacks offset up to a third of forestation's CO2 removal benefits. Science *383*, 860–864. https://doi.org/10.1126/science.adg6196.
47. Betts, A.K., and Ball, J.H. (1997). Albedo over the boreal forest. J. Geophys. Res. *102*, 28901–28909. https://doi.org/10.1029/96JD03876.
48. Mykleby, P.M., Snyder, P.K., and Twine, T.E. (2017). Quantifying the trade-off between carbon sequestration and albedo in midlatitude and high-latitude North American forests. Geophys. Res. Lett. *44*, 2493–2501. https://doi.org/10.1002/2016GL071459.
49. Ménard, I., Thiffault, E., Kurz, W.A., and Boucher, J.-F. (2023). Carbon sequestration and emission mitigation potential of afforestation and reforestation of unproductive territories. Natl. Forum. *54*, 1013–1035. https://doi.org/10.1007/s11056-022-09955-5.
50. Morris, S.J., Conant, R., Mellor, N., Brewer, E., and Paul, E.A. (2010). Controls on Soil Carbon Sequestration and Dynamics: Lessons from Land-use Change. J. Nematol. *42*, 78–83.
51. Schmidt, M.V.C., Ikpeng, Y.U., Kayabi, T., Sanches, R.A., Ono, K.Y., and Adams, C. (2021). Indigenous Knowledge and Forest Succession Management in the Brazilian Amazon: Contributions to Reforestation of Degraded Areas. Front. For. Glob. Change *4*.
52. Brancalion, P.H., Meli, P., Tymus, J.R., Lenti, F.E., M. Benini, R., Silva, A.P.M., Isernhagen, I., and Holl, K.D. (2019). What makes ecosystem restoration expensive? A systematic cost assessment of projects in Brazil. Biol. Conserv. *240*, 108274. https://doi.org/10.1016/j.biocon.2019.108274.
53. Fargione, J., Haase, D.L., Burney, O.T., Kildisheva, O.A., Edge, G., Cook-Patton, S.C., Chapman, T., Rempel, A., Hurteau, M.D., Davis, K.T., et al. (2021). Challenges to the reforestation pipeline in the United States. Front. For. Glob. Change *4*, 629198.
54. Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Synthesis (Island Press).
55. Aguiar, S., Mastrángelo, M.E., Brancalion, P.H., and Meli, P. (2021). Transformative governance for linking forest and landscape restoration

to human well-being in Latin America. Ecosystems and People *17*, 523–538. https://doi.org/10.1080/26395916.2021.1976838.

56. Erbaugh, J.T., and Oldekop, J.A. (2018). Forest landscape restoration for livelihoods and well-being. Curr. Opin. Environ. Sustain. *32*, 76–83. https://doi.org/10.1016/j.cosust.2018.05.007.
57. Dooley, K., Nicholls, Z., and Meinshausen, M. (2022). Carbon removals from nature restoration are no substitute for steep emission reductions. One Earth *5*, 812–824. https://doi.org/10.1016/j.oneear.2022.06.002.
58. Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., and Shukla, P.R. (2018). Global Warming of 1.5 C: IPCC special report on impacts of global warming of 1.5 C above pre-industrial levels in context of strengthening response to climate change, Sustainable Development, and Efforts to Eradicate Poverty (Cambridge University Press).
59. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. In Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, and R. Fradera, et al., eds.. https://doi.org/10.1017/9781009157926.
60. Baldwin, K., Allen, L., Chapman, K., Downing, D., Flynn, N., Mackenzie, W., Major, M., Meades, W., Meidinger, D., Morneau, C., et al. (2018). Vegetation Zones of Canada: A Biogeoclimatic Perspective. [Map] Scale 1:5,000,000 (Natural Resources Canada, Canadian Forest Service).
61. Cao, S. (2008). Why Large-Scale Afforestation Efforts in China Have Failed To Solve the Desertification Problem. Environ. Sci. Technol. *42*, 1826–1831. https://doi.org/10.1021/es0870597.
62. Veldman, J.W., Overbeck, G.E., Negreiros, D., Mahy, G., Le Stradic, S., Fernandes, G.W., Durigan, G., Buisson, E., Putz, F.E., and Bond, W.J. (2015). Tyranny of trees in grassy biomes. Science *347*, 484–485.
63. Fagan, M.E. (2020). A lesson unlearned? Underestimating tree cover in drylands biases global restoration maps. Global Change Biol. *26*, 4679–4690. https://doi.org/10.1111/gcb.15187.
64. Veldman, J.W., Overbeck, G.E., Negreiros, D., Mahy, G., Le Stradic, S., Fernandes, G.W., Durigan, G., Buisson, E., Putz, F.E., and Bond, W.J. (2015). Where Tree Planting and Forest Expansion are Bad for Biodiversity and Ecosystem Services. Bioscience *65*, 1011–1018. https://doi.org/10.1093/biosci/biv118.
65. Environment and Climate Change of Canada (2020). National Inventory Report 1990-2018: Greenhouse Gas Sources and Sinks in Canada (Environment and Climate Change Canada).
66. Agriculture and Agri-Food Canada (2013). Canada Land Inventory (CLI) 1:250,000 - Land Capability for Agriculture. https://open.canada.ca/data/en/dataset/abf04733-8225-4d3c-83fa-9a5b60d43f2e.
67. Agricultural Land Commission (2020). Agricultural Land Reserve. https://www.alc.gov.bc.ca/alc/content/alr-maps/maps-and-gis.
68. ESRI Living Atlas (2022). Ground Surface Elevation - 30m. https://www.arcgis.com/home/item.html?id=0383ba18906149e3bd2a0975a0afdb8e.
69. Government of Canada (2022). Annual Crop Inventory 2021 (Agriculture and Agri-Food Canada). https://open.canada.ca/data/en/dataset/199e4ab6-832b-4434-ac39-e4887d7cc4e5.
70. Grassland Conservation Council of British Columbia (2015). Grassland Ecosystem Mapping and Loss Assessment.
71. Guindon, L., Villemaire, P., St-Amant, R., Bernier, P.Y., Beaudoin, A., Caron, F., Bonucelli, M., and Dorion, H. (2017). Canada Landsat Disturbance (CanLaD) 2017. https://open.canada.ca/data/en/dataset/add1346b-f632-4eb9-a83d-a662b38655ad.
72. ESRI (2022). 2D, 3D & 4D GIS Mapping Software. ArcGIS Pro.
73. Government of Canada (2022). Range Map extents - Species at Risk - Canada. https://open.canada.ca/data/en/dataset/d00f8e8c-40c4-435a-b790-980339ce3121
74. Pither, R., O'Brien, P., Brennan, A., Hirsh-Pearson, K., and Bowman, J. (2023). Predicting areas important for ecological connectivity throughout Canada. PLoS One *18*, e0281980. https://doi.org/10.1371/journal.pone.0281980.
75. McRae, B.H., Dickson, B.G., Keitt, T.H., and Shah, V.B. (2008). Using Circuit Theory to Model Connectivity in Ecology, Evolution, and Conservation. Ecology *89*, 2712–2724. https://doi.org/10.1890/07-1861.1.
76. Hunt, L.M., and Haider, W. (2004). Aesthetic impacts of disturbances on selected boreal forested shorelines. Forensic. Sci. *50*, 729–738.
77. Rowe, J.S. (1972). Forest regions of Canada (Canadian Forestry Service).
78. McKenney, D.W., Yemshanov, D., Fox, G., and Ramlal, E. (2004). Cost estimates for carbon sequestration from fast growing poplar plantations in Canada. For. Pol. Econ. *6*, 345–358. https://doi.org/10.1016/j.forpol.2004.03.010.
79. Nielsen, A.S.E., Plantinga, A.J., and Alig, R.J. (2014). New Cost Estimates for Carbon Sequestration through Afforestation in the United States (U.S. Department of Agriculture, Forest Service).
80. Plantinga, A.J., Lubowski, R.N., and Stavins, R.N. (2002). The effects of potential land development on agricultural land prices. J. Urban Econ. *52*, 561–581. https://doi.org/10.1016/S0094-1190(02)00503-X.
81. Winsten, J., Walker, S., Brown, S., and Grimland, S. (2011). Estimating carbon supply curves from afforestation of agricultural land in the Northeastern U.S. Mitig. Adapt. Strategies Glob. Change *16*, 925–942. https://doi.org/10.1007/s11027-011-9303-0.
82. Statistics Canada (2022). Census of Agriculture. https://www.statcan.gc.ca/en/census-agriculture.
83. Statistics Canada (2022). Farm capital, Census of Agriculture, 2021. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210023701.
84. Statistics Canada (2022). Land tenure, Census of Agriculture, 2021. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210023401.
85. Poley, L.G., Schuster, R., Smith, W., and Ray, J.C. (2022). Identifying differences in roadless areas in Canada based on global, national, and regional road datasets. Conserv. Sci. Pract. *4*, e12656. https://doi.org/10.1111/csp2.12656.
86. Hanson, J., Schuster, R., Morrell, N., Strimas-Mackey, M., Edwards, B., Watts, M., Arcese, P., Bennett, J., and Possingham, H. (2022). prioritizr: Systematic Conservation Prioritization in R. Version 7.2.2.
87. R Core Team (2023). R: A Language and Environment for Statistical Computing (R Foundation for Statistical Computing).
88. Gurobi Optimization, LLC (2023). Gurobi Optimizer Reference Manual.