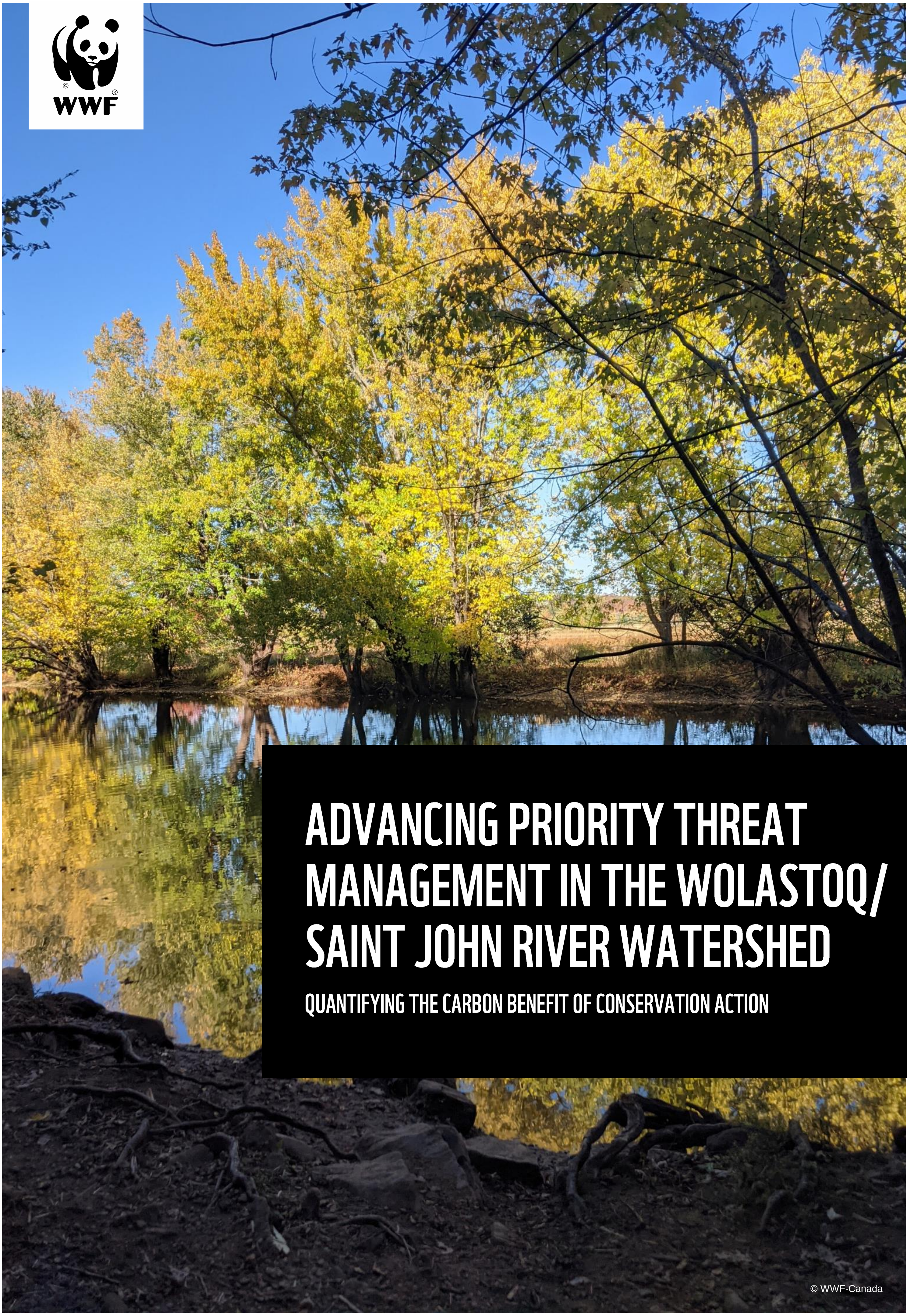

ADVANCING PRIORITY THREAT MANAGEMENT IN THE WOLASTOQ/ SAINT JOHN RIVER WATERSHED

QUANTIFYING THE CARBON BENEFIT OF CONSERVATION ACTION

Special thanks for review and support to: Abbey Camaclang (University of British Columbia), Tara G. Martin (University of British Columbia), Camile Sothe (McMaster University), Alemu Gonsamo (McMaster University), Will Merritt (WWF-Canada)

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EMBRACING THE INTERCONNECTEDNESS OF CLIMATE CHANGE AND WILDLIFE

Nature is under threat. The dual crises of biodiversity loss and climate change are cumulatively affecting the natural world and the many societal benefits that we derive from healthy, resilient ecosystems. [i] The climate crisis is reinforcing and exacerbating the biodiversity crisis (and vice versa),[ii] with fires, floods and sea-level rise gradually becoming part of the colloquial lexicon. In less than a century, human-driven climate change has warmed our lands and seas, causing widespread, rapid and extreme changes across the natural world.[iii] Yet nature itself can inherently help us fight both climate change and biodiversity loss simultaneously.[iv] Specifically, nature-based climate solutions (NbCS) — like protecting intact ecosystems and restoring degraded habitats — can help us build a stronger, more resilient future for wildlife, climate and people.[v] [vi]

Nature is an extremely powerful tool for taking excess carbon emissions out of the atmosphere. For example, the leaves, stems and roots of plants sequester dangerous greenhouse gas emissions from the atmosphere and bury them into our soils — a natural phenomenon that helps regulate Earth's climate. Yet, because our collective human footprint is expanding, nature's ability to regulate climate is decreasing. Human activity has already modified 77 and 87 per cent of Earth's land (excluding Antarctica) and oceans, respectively[vii] [viii] [ix] — actions that not only impact habitat for wildlife, but also release nature's stored carbon back into the atmosphere, thereby contributing to the climate crisis.

This report aims to build upon our previous conservation planning work in the Wolastoq/Saint John River (SJR) watershed by assessing the carbon benefit of selected biodiversity conservation actions and strategies. Given the inherent interconnectedness of the biodiversity and climate crises, we can be more effective and efficient in our approach to conservation if we consider both the biodiversity and carbon benefits of conservation actions. This report serves to complement the Priority Threat Management framework that was applied to the Wolastoq/SJR watershed in 2020.[x] Taken together, these two reports provide a preliminary framework for NbCS in the region.

CARBON STORAGE IN THE WOLASTOQ/SJR WATERSHED

Lands and waters can both actively reduce atmospheric carbon through sequestration and store that carbon over the long term. In fact, large carbon stores are found throughout the Wolastoq/SJR watershed in wetlands, peatlands and forests. While healthy, resilient and diverse ecosystems store carbon, the disruption or degradation of nature can ultimately release carbon back into the atmosphere, thereby accelerating climate change and threatening biodiversity. The watershed has a carbon store roughly equivalent to 5,066 Mt CO_2e (Figure 1), the majority of which is found beneath our feet in soils, roots and saturated ecosystems such as wetlands. This is equivalent to about one-seventh of annual global emissions.

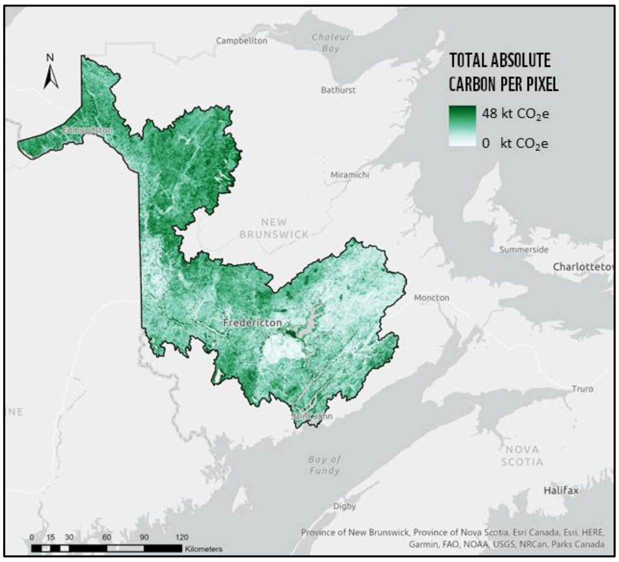

Figure 1. Total absolute carbon per pixel within the Wolastoq/SJR watershed (0-48 kt CO_2e). Colour gradient classified by two standard deviations. Total absolute carbon data derived from combining recent estimates of biomass and soil carbon nationally.[xi]

PRIORITY THREAT MANAGEMENT

CONSERVATION PLANNING IN THE WOLASTOQ/ SAINT JOHN RIVER WATERSHED

Priority Threat Management (PTM) is a decision support framework that facilitates the rapid identification of effective conservation strategies and evaluates how budgets can be best allocated to benefit the greatest number of species.[xii] Led by Dr. Tara G. Martin, the Martin Conservation Decisions Lab at the University of British Columbia has been applying the framework to key ecological regions across Canada, including the South of the Divide in Saskatchewan,[xiii] the Fraser River Estuary[xiv] and, in collaboration with WWF-Canada, the Wolastoq/SJR watershed.[xv] The PTM framework specifically differs from other management approaches in that it integrates the costs, benefits and feasibilities of management actions. The framework relies heavily on expert elicitation to collect the relevant data.[xvi]

The PTM approach was applied to the Wolastoq/SJR watershed to develop a prioritization of conservation strategies that could help recover species of conservation concern. However, the approach taken in 2020 focused on biodiversity explicitly and did not incorporate climate change mitigation as an additional benefit of conservation action.

This report assesses select actions through the lens of climate change mitigation, providing a more holistic approach for NbCS. By implementing conservation actions that provide both biodiversity and climate benefits in the Wolastoq/SJR watershed, we can be more effective and efficient in our approach — enhancing natural benefits of conservation action, ensuring feasibility of implementation and reducing associated costs.

BIODIVERSITY OUTCOMES FOR PTM IN THE WOLASTOQ/SJR WATERSHED

Before we dig into the outcomes, it may be useful to summarize the biodiversity outcomes for PTM in the Wolastoq/SJR watershed.

Nine ecological groups comprised of 45 species and one forest community were incorporated into the PTM analysis.[xvii] Under the “business-as-usual” scenario, experts estimated that none of the ecological groups had a high chance (≥ 60 per cent) of functional persistence — that is, having viable, self-sustaining populations that continue to perform their ecological function over 25 years. This outcome indicates that current investments of financial resources, time and capacity are likely insufficient for biodiversity to persist, let alone thrive, in the watershed.[xviii] [xix] However, additional investments and a prioritized approach to species recovery can help secure most of these biologically and culturally significant species. Notably, all strategies identified by the experts would need to be implemented to secure the greatest number of species, but in terms of prioritization, there are two key steps.[xx]

Land management — including public, private (agricultural) and forestry land conservation actions — is anticipated to have the greatest overall benefits for biodiversity, securing a total of five ecological groups (30 species) to a ≥ 60 per cent chance of persistence at a cost of $1.2 million per year. Generally, the strategy focuses on protected and conserved areas and the implementation of best management practices on private lands.

With the land management strategy underway, the analysis then prioritizes aquatic habitat management and policy. This strategy helps to secure an additional ecological group (four more species) and has an implementation cost of $7.5 million per year. The strategy includes all aquatic ecosystems, such as riparian areas, wetlands and rivers, focusing on policies related to enhanced protection of ecological services and biodiversity, as well as restoration and education.

QUANTIFYING THE CARBON BENEFIT OF CONSERVATION ACTION: METHODS AND APPROACHES

WWF-Canada sought to evaluate the carbon benefits of selected conservation actions and strategies identified through the PTM analysis via a post-hoc approach. To date, few PTM studies have incorporated additional societal and/or environmental benefits[xxi] beyond the primary application of biodiversity conservation into a PTM or complementary post-hoc analysis, and none has incorporated carbon through the lens of NbCS (e.g., carbon storage and sequestration in natural ecosystems).

We integrated carbon considerations in a post-hoc manner for this report. Ideally, estimates of the additional benefits of management actions would be integrated into the expert elicitation process, when the feasibility, costs and benefits of management actions are estimated at a facilitated PTM workshop. However, as climate change mitigation was not part of the original scope of the PTM analysis in the Wolastoq/SJR watershed, experts did not quantify from the outset the carbon benefits of conservation actions.

The carbon benefits evaluated in this analysis are specific to carbon storage and sequestration in natural ecosystems — through avoided emissions and active removals, respectively — as a means of mitigating climate change. The approach leveraged key WWF-Canada resources and documents, including *Mapping Canada's Carbon Landscape* [xxii] and the *Wildlife Protection Assessment*.[xxiii]

From a scoping perspective, only management actions with direct carbon benefits (e.g., planting vegetation, protected areas) are included in our analysis, recognizing that indirect benefits (e.g., policy changes, educational programs) can be more widespread and difficult to quantify and may integrate higher levels of uncertainty.[xxiv] The analysis presented here had a focal biodiversity approach with carbon quantified separately, meaning that the strategies and actions were developed and prioritized primarily from a biodiversity conservation perspective.

We assessed the conservation strategies and actions identified to enhance biodiversity to evaluate their carbon benefits through the broader lens of NbCS, including both avoided emissions (e.g., protection) and removals (e.g., restoration). **Detailed methods are outlined in the appendix.** Eight actions were selected for quantifying direct carbon co-benefits. Using modelled, spatially explicit carbon storage estimates[xxv] for protection, as well as an analysis of carbon sequestration estimates for restoration, we evaluated the potential for natural carbon storage and sequestration to support climate change mitigation. Importantly, the estimated carbon values presented here represent best estimates according to the information available, and do not fully account for incomplete data, the criteria of additionality (i.e., over-and-above business as usual), future degradation of ecosystems and continued carbon sequestration of intact landscapes. Accordingly, the carbon estimates provided primarily serve to guide management actions at a broad scale.

CARBON BENEFIT OF CONSERVATION ACTION

CROSS-WALKING PRIORITY ACTIONS FOR BIODIVERSITY AND CARBON

Critically, the tiered approach outlined in the original PTM analysis for the Wolastoq/SJR watershed aligns with the independent quantification of carbon benefits for selected conservation strategies.

Importantly, implementation of all strategies identified throughout the process would ultimately garner the greatest long-term benefits for both biodiversity and climate change. Yet, while all conservation strategies are needed, they can be prioritized (by time, capacity and financial resources) based upon the greatest overall benefits.

As a first step, existing and new conservation funds should be allocated to focus on Land Management (a combination of public, private and forest land management), which could secure five ecological groups and yield the greatest carbon benefits, as estimated through total carbon storage and vulnerable carbon (e.g., avoided emissions). Once Land Management is adequately resourced, the next step would be to focus on Aquatic Management (a combination of four individual strategies). This approach could secure an additional ecological group, providing biodiversity and climate change benefits by actively removing carbon from the atmosphere (i.e., sequestration) and ensuring carbon stays locked in nature (i.e., storage). Only one other action identified through the original PTM process (geared toward biodiversity) was anticipated to have direct climate change benefits that were quantifiable with limited uncertainty: Climate Change Policies and Actions.

LAND MANAGEMENT

i. Protected and conserved areas

Protected areas are a cornerstone of wildlife conservation and are increasingly referenced as valuable nature-based climate solutions to avoid conversion or degradation of natural carbon stores.

Designation and stewardship of protected areas serve to safeguard biodiversity and, by preventing the potential release of greenhouse gas emissions into the atmosphere if disrupted, protect important carbon stores. As such, the carbon benefit of protected and conserved areas is specific to carbon storage and avoided emissions, rather than active removals.

In 2019, the New Brunswick government committed to protecting 10 per cent of the province's terrestrial lands and freshwater effectively doubling the amount of conserved land (4.6 per cent) with the support of $9.3 million from the federal government's Canada Nature Fund.[xxvi] This investment was meant to contribute to Pathway to Canada Target 1, an initiative between federal, provincial and territorial governments to protect at least 17 per cent of terrestrial and freshwater areas by 2020. As of December 2020, 4.85 per cent of terrestrial and freshwater areas had been designated or established for protection in New Brunswick (Figure 2),[xxvii] though the establishment of additional areas is anticipated shortly.

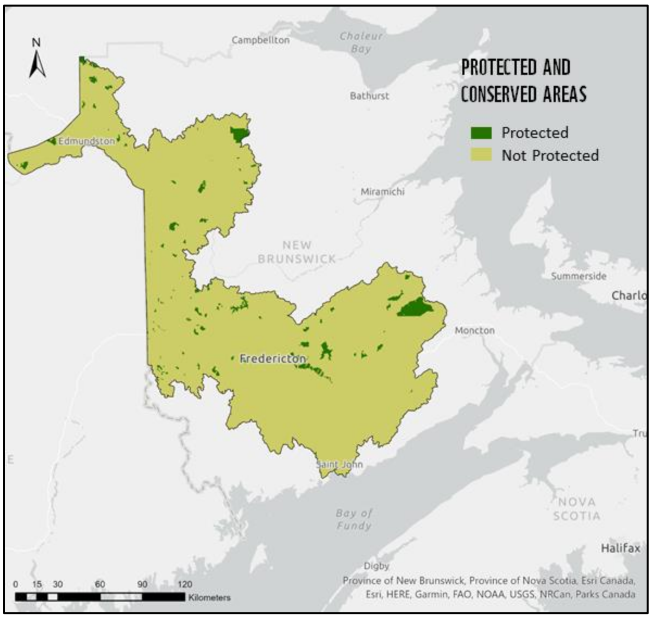

Figure 2. Protected and conserved areas designated or established throughout the Wolastoq/SJR watershed.

Despite the country falling short of its intended targets, goal setting did not end in 2020. In fact, the Government of Canada recently expanded on previous targets for protected areas, committing to an interim target of 25 per cent of terrestrial and freshwater areas protected or conserved by 2025[xxviii] and building to 30 per cent by 2030, which aligns with international recommendations for more ambitious targets for protected areas.[xxix] [xxx] Still, action cannot fall short of intention, or else we will fail to address biodiversity loss and climate change in the Wolastoq/SJR watershed and around the world.

Results

The PTM Land Management strategy adopts a 17 per cent protection target (or 12,411 km^2) for New Brunswick, which is in alignment with 2020 national commitments but more ambitious than current provincial commitments. Currently, protected and conserved areas listed as “designated” or “established” (including interim) cover 4.85 per cent of New Brunswick. That leaves an outstanding gap of 12.15 per cent (8,870 km^2) to achieve 17 per cent protection. The Wolastoq/SJR watershed occupies 39.94 per cent of New Brunswick, suggesting that a reasonable target for additional protected and conserved areas in the region is 3,542 km^2 (8,870 km^2 x 0.3994). We used spatially explicit carbon storage estimates to evaluate the total carbon stock within 3,542 km^2 of the Wolastoq/SJR watershed (**see the appendix for methods**). We multiplied the target for additional protected and conserved areas (3,542 km^2) by the average carbon density for areas lacking current protection (47,337 t C/km^2) in the Wolastoq/SJR watershed, in order to evaluate the total carbon stock (615 Mt CO_2e) that could remain locked in nature if the proposed protected area target is met.

We estimate that approximately 615 Mt CO_2e could remain stored in ecosystems by protecting and conserving an additional 3,542 km^2 of land and freshwater. Importantly, this value represents the estimated stock of presently stored carbon (i.e., does not consider additional carbon sequestered over time with protection) and does not account for the vulnerability of carbon (e.g., avoided emissions; whether development poses imminent threat to the carbon stock), nor for the potential for human disruption (as protection does not guarantee that ecosystems will be free from human pressures). If protected and conserved areas were established to maximize the protection of carbon stores, the estimated carbon value could be larger.

KEY FINDING: CONSIDERATION OF VULNERABLE CARBON STORES

In reality, only some areas in the Wolastoq/SJR watershed would be vulnerable to land-use degradation and land-use change. We evaluated changes in land cover for the Wolastoq/SJR watershed from 1992 to 2020 and found that the majority of the area (98 per cent) remained in the same land-use category. Of the area that transitioned to a different land cover class, nearly 60 per cent was modified from natural to human-dominated land cover classes (croplands, urban landscapes and barren lands). To assess the avoided emissions of protecting ecosystems, the vulnerability of the area to degradation and/or conversion (e.g., land cover change) must be taken into account. **The rate of land cover conversion in the region therefore suggests that 6.1 Mt CO_2e is vulnerable to land-use change by 2050** — not accounting for ecological degradation (e.g., harvesting forested landscapes), which could substantially increase the amount of vulnerable carbon in the region given the large forestry footprint within the Wolastoq/SJR watershed. Consequently, by achieving the 17 per cent target, we could avoid the release of 6.1 Mt CO_2e to the atmosphere — which equals roughly 50 per cent of the province’s overall greenhouse gas emissions in 2019.[xxxi]

With over 80 per cent of the Wolastoq/SJR watershed covered in forest[xxxii], forestry is one of the province’s most widespread economic sectors.[xxxiii] On average, 769km^2 of forest have been harvested within the province each year (over the last six years).[xxxiv] If New Brunswick had protected the amount of forest area harvested in the province over the last six years, the protected areas target for the Wolastoq/SJR watershed could have been met.

ii. Identifying the 'where'

While percentage-based area targets are necessary and have certainly driven protected area expansion in Canada and around the world, quantitative targets alone are insufficient to conserve biodiversity wholly and safeguard important carbon stores.[xxxv] To maximize the benefits of protected areas, we need an enhanced focus on the designation and management of areas of high importance for wildlife as well as carbon storage and sequestration. This ensures benefits for local communities while advancing the rights of and responsibilities to Indigenous Peoples through commitments rooted in the principles of the United Nations Declaration on the Rights of Indigenous Peoples.

WILDLIFE PROTECTION ASSESSMENT

In 2019, WWF-Canada's Wildlife Protection Assessment evaluated the ecological representation of Canada's current protected areas network and found that the wide variety of physical habitats that wildlife need are not sufficiently protected. Within New Brunswick, only 1 per cent of physical habitats were considered adequately represented within the province's protected area network (Figure 3). A staggering 56 per cent of physical habitats were categorized as inadequately protected, while 43 percent had no protection whatsoever. Consequently, many areas in the Wolastoq/SJR watershed are considered a national priority for the designation of new protected areas (Figure 4).

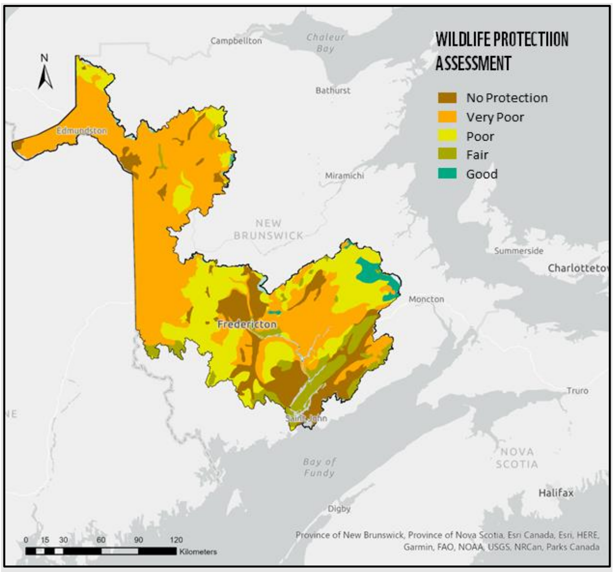

Figure 3. Ecological representation of protected areas in the Wolastoq/SJR watershed according to WWF-Canada's Wildlife Protection Assessment. A classification of "good" or "great" is considered adequate representation. All other classifications are considered inadequate to protect wildlife effectively.

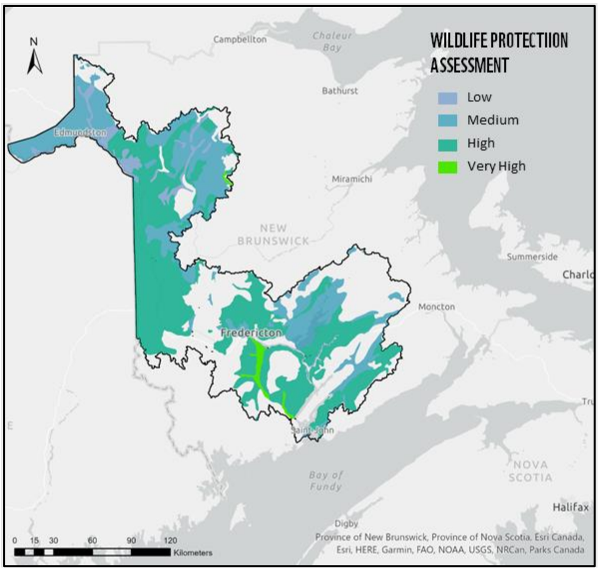

Figure 4. Prioritization of areas in need to protection to enhance the ecological representation of Canada's protected areas network, while also considering biodiversity and climate change benefits. All coloured areas are considered to be of priority, with the colour scale representing the relative priority for the designation of new protected areas.

Results

Within the PTM Land Management strategy, identification and protection of key areas for specific species was identified as a critical action, particularly for (i) rare and restricted plant and lichen communities, and (ii) bat maternity colonies and winter hibernacula. If these habitats were afforded protection, approximately 14 Mt CO_2e and 10 Mt CO_2e, respectively, could remain locked in nature. These areas are not considered additional to the PTM action to protect 17 per cent of New Brunswick's lands and freshwater; instead, they help refine the boundaries of which areas we should prioritize for protection. Consequently, the same limitations (e.g., assessment of vulnerability) of protected areas assessments (e.g., protecting 17 per cent of New Brunswick's lands and freshwater) apply.

iii. Identifying the 'how'

Continued support for the designation of new protected areas in the region is crucial to deliver clear benefits to biodiversity and ecosystems, as well as the benefits that humans derive from resilient systems, including clean air, carbon sequestration, pollination and avoidance of disease.[xxxvi] New protected areas will also require additional funding to ensure that they are afforded the necessary protections and management to recover biodiversity.[xxxvii] For these reasons, experts involved in the PTM process identified capital investment in endowment funds for purchasing land to contribute to protected areas targets as a key action within the Land Management strategy, particularly for private land purchases.

AQUATIC MANAGEMENT

i. Protection and policy

In New Brunswick, wetlands are managed through the New Brunswick Wetlands Conservation Policy and the Watercourse and Wetlands Alteration Regulation under the Clean Water Act. The current policy, however, only applies to regulated wetlands that are provincially significant, contiguous to a watercourse or >1 hectare in size[xxxviii] (about the size of two football fields). Anything else lacks adequate policy protection. Consequently, the health and natural function of small wetlands are not protected despite their importance for habitat and implications for land-use planning and management in forestry and agriculture. This is particularly important as the number of wetlands per area increases with decreasing wetland size,[xxxix] meaning small wetlands are significant.

Wetlands also store a disproportionate amount of global soil carbon: between 20 to 30 percent, despite occupying a small percentage of Earth's land surface.[xl] Consequently, disruption of these habitats can have strong implications for the regulation of Earth's climate. Wetlands cover approximately 5 per cent of New Brunswick[xli] — yet, as mentioned, not all wetlands are protected.

Results

By protecting all currently mapped small wetlands within the Wolastoq/SJR watershed, we can ensure that 32 Mt CO_2e remains stored in these important habitats. This value represents the maximum potential for avoided emissions of presently stored carbon (i.e., does not consider additional carbon sequestered over time with protection), and does not account for the vulnerability of carbon (e.g., avoided emissions), nor for the potential for human disruption (as protection does not guarantee that ecosystems will be free from human pressures).

ii. Reducing impacts and restoring habitats

Hundreds of years of colonial activity have threatened the Wolastoq/SJR watershed, resulting in habitat loss and degradation, invasive species, pollution and conditions that are more susceptible to climate change impacts.[xlii] [xliii] Moreover, further degradation exacerbates the environmental crises that we're facing today. Protection of intact ecosystems and sustainable management of degraded ecosystems will not adequately address biodiversity loss and climate change — we must also rebuild and restore what's been lost. The UN Decade on Ecosystem Restoration (2021-2030)[xliv] is based on this concept and emphasizes that preventing, halting and reversing the degradation of ecosystems around the world is essential to addressing myriad environmental and societal issues. Likewise, experts involved in the development of the PTM conservation strategies identified the critical need for restoring aquatic and terrestrial ecosystems in the Wolastoq/SJR watershed. Restoration is not only an important action for protecting species at risk, but also a key nature-based climate solution, directly contributing carbon benefits for climate change mitigation and adaptation and ensuring resiliency for generations to come.

While broad-scale restoration has the potential to be an effective tool for addressing both biodiversity loss and climate change, results can take many decades. The difference, however, is that while protection is needed to prevent the loss of wildlife and degradation of carbon stores, restoration can help actively recover biodiversity[xlv] and sequester climate-change-causing carbon[xlvi] [xlvii] (through the active removal of emissions, rather than the avoidance of emissions). Ultimately, ecological restoration serves to repair the damage that humans have done to the natural environment.

Results

Reducing or removing current pressures, threats and impacts — including removing barriers to fish passage, reducing stormwater discharge and runoff and regulating development of shorelines[xlviii] — is also essential for enabling the recovery of degraded wetlands, streams and shorelines.[xlix] For instance, in the Wolastoq/SJR watershed, regulating shoreline development of the lakes with Prototype Quillwort could help protect a carbon store of 0.05 Mt CO_2, while further restoration in these aquatic systems may enhance quantitative carbon sink values and improve habitat and ecosystem functioning.

CLIMATE CHANGE POLICIES AND ACTIONS

Like all other PTM conservation actions developed for the Wolastoq/SJR watershed, the Climate Change Policies and Actions were originally drafted solely from a biodiversity perspective. Consequently, the strategy in its current form lacks key actions that may have more substantial carbon storage and sequestration benefits (e.g., planting trees rather than flowers). Accordingly, the anticipated carbon benefits are smaller than if the actions had been created with both biodiversity and climate change goals in mind. The actionable line items with calculable carbon benefits are specific to planting and maintaining flowering plants, through a grant program aimed at planting approximately 2,000 plants (or 6,000m^2) per year for 10 years. These actions are estimated to result in a cumulative carbon sequestration (meaning direct removals of emissions currently in the atmosphere) of 22.2 tonnes CO_2 by 2050. While the climate change mitigation benefit may be comparatively small, planting early flowering vegetation is helpful for maintaining food availability for bees, other insects and the broader food web.

SUMMARY

Canada has a great opportunity — and responsibility — to demonstrate how nature-based climate solutions can be implemented to increase measurable reductions of atmospheric carbon and reverse the trend of wildlife loss, while doing so in an inclusive and equitable way that upholds Indigenous rights and empowers Indigenous leadership. This is also an opportunity to deliver integrated programs that deliver multiple societal benefits, including building climate resilience and supporting the recovery of at-risk species.

Priority Threat Management (PTM) analysis has put a plan in place for the Wolastoq/SJR watershed to address biodiversity loss, but many of the identified strategies and actions also provide carbon benefits. Land management strategies, particularly protected and conserved areas, provide the greatest biodiversity and carbon benefits, estimated through PTM and independent post-hoc analysis, respectively. By halting the disruption and degradation of our ecosystems, we can ensure that ecosystem carbon remains locked in nature. This is particularly timely, given commitments by provincial and federal governments on the establishment of protected and conserved areas. By protecting the right places — those with large carbon stores and species at risk — we can enhance our conservation impact now and into the future.

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APPENDIX - METHODS

A Priority Threat Management (PTM) analysis was completed for the Wolastoq/SJR watershed in 2020. The Priority Threat Management Handbook[l] details the methods and data required to conduct a PTM analysis. To date, few studies have incorporated additional societal and environmental benefits[li] beyond the primary application of biodiversity conservation into a PTM or complementary post-hoc analysis, and none has incorporated carbon through the lens of nature-based climate solutions (NbCS) (e.g., carbon storage and sequestration in natural ecosystems). Ideally, estimates of the benefits of management actions for carbon storage and sequestration would be integrated into the expert elicitation process, when the feasibility, costs and biodiversity benefits of management actions are estimated. However, the PTM analysis in the Wolastoq/SJR watershed was not set up to accommodate the inclusion of carbon benefits from the outset; consequently, we have assessed carbon considerations in a post-hoc manner for this report.

In theory, there are different ways to integrate estimates of additional benefits into a PTM analysis.[lii] Ideally, a single performance metric should be used to assess both the biodiversity and climate benefits of management actions. However, defining a single unit of measurement (e.g., the probability of persistence of species) that is applicable to multiple ecosystem and societal benefits is challenging. For instance, “probability of persistence” is not a useful metric for carbon benefits, nor is “carbon storage” useful from a biodiversity perspective. Another option is to analyze conservation strategies that have secondary benefits and highlight these strategies for decision makers to consider. If other benefits are included, the value of undertaking a strategy would be greater than estimated from the biodiversity benefits alone.

From a scoping perspective, only management actions with direct carbon benefits (e.g., planting vegetation, protected areas) are included in our analysis, recognizing that indirect benefits (e.g., policy changes, educational programs) can be more widespread and difficult to quantify and may integrate higher levels of uncertainty.[liii] The analysis presented here had a focal biodiversity approach with carbon included as an additional benefit — meaning that the strategies and actions were developed and prioritized primarily from a biodiversity conservation perspective, and we are simply evaluating the additional benefit of climate change mitigation through both avoided emissions (e.g., protection) and sequestered carbon (e.g., restoration) for some conservation actions. If conservation strategies had initially been designed to maximize benefits to both biodiversity and climate, they may have been different (e.g., planting trees vs. annual flowers).

By evaluating the carbon benefit of biodiversity conservation strategies, WWF-Canada sought to incorporate carbon benefits into the PTM biodiversity analysis in the Wolastoq/SJR watershed via a post-hoc approach. Of the 56 individual actions (included within 15 conservation strategies) identified for biodiversity conservation in the Wolastoq/SJR watershed (within the context of a set of 45 species and one forest community), eight actions were selected for evaluating carbon benefits (Table S1; S2). The selection of actions relied on three components:

- Direct carbon benefits (e.g., restoring habitat, as opposed to best management practices for green infrastructure, which would be considered indirect)
- Quantification of action implementation (e.g., area of land restored; amount of habitat protected)
- Reasonable quantifiable estimate for avoided emissions or removals (e.g., removal of actions with high uncertainty)

We used modelled, spatially explicit carbon storage estimates for protection and an analysis of carbon sequestration estimates for restoration to evaluate the potential for both avoided emissions and active removals to support climate change mitigation. Given the limitations of predicting future impacts on habitats, the estimates presented encompass potential values rather than actual benefits. Moreover, estimates have been divided into total carbon stock, vulnerable carbon stock (i.e., avoided emissions) and active removals, though it's important to note that in practice, the divide is more ambiguous. For instance, designation of a protected and conserved area would not only help avoid emissions that would be released if this natural area was destroyed, but the natural ecosystems within the boundary may continue to sequester carbon (i.e., actively remove carbon) over time. Accordingly, the carbon estimates provided primarily serve to prioritize management actions at a broad scale.

Table S1. Summary of carbon storage and sequestration showing minimum, maximum, mean and total carbon storage estimates (Mt CO_2) for strategies and actions identified as having a noteworthy carbon benefit from the original Priority Threat Management biodiversity analysis within the Wolastoq/SJR watershed.

STRATEGY	ACTION	AREA (km^2)	MIN (Mt CO_2e)	MAX (Mt CO_2e)	MEAN (Mt CO_2e)	STD (Mt CO_2e)	TOTAL (Mt CO_2e)	DENSITY (Mt CO_2e/ km^2)
17: Land management	**Protect 17% of New Brunswick**	3,542.44	0.002	0.048	0.008	0.002	614.861	0.174
	Bats	66.06	0.003	0.030	0.008	0.003	10.293	0.156
	Plants	103.06	0.004	0.025	0.008	0.003	13.735	0.133
18: Aquatic management	**Protect wetlands**	200.13	0.002	0.038	0.007	0.002	31.970	0.133
	Wetland, shoreline and stream restoration	NA	NA	NA	NA	NA	NA	NA
	Prototype Quillwort (shoreline development)	0.26	0.007	0.028	0.013	0.008	0.053	0.208
16: Climate change policies and actions	**Planting and maintaining flowering plants**	0.06	0	2.2E-05	NA	NA	2.2E-05	3.7E-03

STRATEGY 17: LAND MANAGEMENT

Action: Protecting 17 per cent of New Brunswick's lands and freshwater (integrating public and private lands)

Spatially explicit carbon storage estimates (at a 250m resolution)[liv] in the Wolastoq/SJR watershed boundary — including carbon in biomass and soils to a 2m depth — were used to derive quantitative estimates of carbon stocks for designating and establishing new protected and conserved areas. Protected areas in New Brunswick currently listed as "designated" or "established" (including interim) were selected from the Canadian Protected and Conserved Areas Database (CPCAD).[lv] Combined, these areas cover 4.85 per cent of New Brunswick, representing 3,540 km^2. To achieve 17 per cent protection for New Brunswick (12,410 km^2), there is an outstanding gap of 12.15 percent (8,871 km^2). The Wolastoq/SJR watershed occupies 39.94 per cent of New Brunswick, suggesting that a reasonable target for additional protected and conserved areas in the region is 3,542 km^2 (8,870 km^2 x 0.3994).

To estimate the amount of carbon within the proposed target for additional protected and conserved areas (3,542 km^2), the amount of carbon currently found in protected areas in the Wolastoq/SJR watershed (44 Mt C) was subtracted from the total amount of carbon within the Wolastoq/SJR watershed boundary (1,381 Mt C). Similarly, the total land area within protected areas in the Wolastoq/SJR watershed (896 km^2) was subtracted from the total area of the Wolastoq/SJR watershed boundary (29,155 km^2) to produce a value of carbon density for areas currently lacking protection (47,337 t C/km^2). We multiplied the target for additional protected and conserved areas in the Wolastoq/SJR watershed (3,542 km^2) by the carbon density for areas lacking current protection (47,337 t C/km^2) to evaluate the additional carbon stock (168 Mt C; 615 Mt CO_2e) secured by reaching the proposed protected area target for the Wolastoq/SJR watershed. Importantly, this value represents presently stored carbon (i.e., does not consider additional carbon sequestered over time with protection), and does not account for the vulnerability of carbon (e.g., avoided emissions), nor for the potential for human disruption (as protection does not guarantee that ecosystems will be free from human pressures).

In reality, only some areas in the Wolastoq/SJR watershed would be vulnerable to land-use degradation and land-use change even in the absence of protected area designation. We evaluated changes in land cover for the Wolastoq/SJR watershed from 1992 to 2020 using land cover data at a 30m resolution.[lvi] Notably, the majority of the area (98 per cent) remained in the same land-use category over this period. Of the area that transitioned to a different land cover class, nearly 60 per cent was modified from natural to human-dominated land cover classes (croplands, urban landscapes and bare areas). To assess the avoided emissions of protecting ecosystems (and claim the carbon benefits), the vulnerability of the area to degradation and/or conversion must be taken into account. As specific sites for designation as protected areas were not explicitly identified for this analysis, we can only estimate the potential for avoided emissions of stored carbon based on average rates of land conversion in the region. The rate of land cover conversion in the region therefore suggests that 6.1 Mt CO_2e is vulnerable to land-use change by 2050. Note that degradation is also critically important but not accounted for here. Accounting for ecological degradation (e.g., due to harvesting forested landscapes) could substantially increase the amount of vulnerable carbon in the region given the large forestry footprint within the Wolastoq/SJR watershed.

Action: Capital investment in endowment funds for land purchases to contribute to 17 per cent target

This investment is not considered to be additional to the strategy to protect 17 per cent of New Brunswick's lands and freshwaters. Rather, this action supports *how* protection targets will be achieved — specifically for private lands. Critically, the cost of protecting land differs spatially, temporally and among individual owners.

Action: Identifying and protecting occurrences of specific species

Spatially explicit carbon storage estimates[lvii] were also relied upon to derive quantitative estimates of total carbon stocks for specific species locations. These estimates are considered conservative given that not all species and/or locations have been identified and mapped. For instance, there were no data available for twayblade, black foam lichen and tri-coloured bat, and very few records of occurrence for the other species on the list. Species occurrences were provided by the Atlantic Canada Conservation Data Centre,[lviii] with point locations buffered by the uncertainty value (m^2). Records prior to 1960 or with no date (n.d.) were removed. The total carbon storage within each buffered location was derived by overlaying buffered locations with spatially explicit carbon storage estimates.[lix]

- Plants: Anticosti aster; pinedrops; Furbish's lousewort
    - Total CO_2e: 13.7 Mt
- Bats: Little brown myotis; Northern long-eared myotis
    - Total CO_2e: 10.3 Mt

These areas are not considered additional to the strategy to protect 17 per cent of New Brunswick's lands and freshwater; instead, they help refine the boundaries of which areas should be prioritized for protection. Consequently, the same limitations of the previous analysis (e.g., protecting 17 per cent of New Brunswick's lands and freshwater) apply. Specifically, this value represents presently stored carbon (i.e., does not consider additional carbon sequestered over time with protection), and does not account for the vulnerability of carbon (e.g., avoided emissions), nor for the potential for human disruption (as protection does not guarantee that ecosystems will be free from human pressures).

18: AQUATIC MANAGEMENT

Action: Identify and map small wetlands and improve wetland policy for these areas; implement wetland strategy on private land

Quantitative estimates of total carbon stock for small wetlands (≤ 1ha) not currently protected through provincial regulation were derived from spatially explicit carbon storage estimates.[lx] The values reported are considered a best estimate given that (i) only some small wetlands (≤ 1ha) have been mapped, and (ii) not all wetlands covered under current legislation have been tagged within the dataset. Wetlands ≤ 1ha and lacking Provincially Significant Wetlands (PSW) status were selected from the GeoNB dataset.[lxi] A 30m buffer was applied to these areas, representing the protection they would receive. The total carbon storage (31.9 Mt CO_2) was estimated by overlaying the selected buffered wetlands with spatially explicit carbon storage estimates.[lxii]

Importantly, this value represents presently stored carbon (i.e., does not consider additional carbon sequestered over time with protection), and does not account for the vulnerability of carbon (e.g., avoided emissions), nor for the potential for human disruption (as protection does not guarantee that ecosystems will be free from human pressures). For instance, proponents can apply for a permit to degrade, disrupt or convert a wetland.[lxiii]

Action: Wetland, shoreline and stream restoration

This strategy and associated action involved a high degree of assumptions, which therefore limited its suitability for the analysis of carbon benefits. However, aquatic restoration is a key nature-based solution, directly contributing carbon benefits for climate change mitigation (and adaptation). Consequently, the qualitative contribution of restoration — rather than a quantitative value for carbon sequestration — was described in the report.

Unfortunately, restoration actions identified through the expert elicitation process lacked spatial information (i.e., the total area needed for restoration was not specified). In the absence of an area-based measure, meaningful estimation of the potential for carbon sequestration is difficult. To obtain an area-based measure, we asked practitioners in the Wolastoq/SJR watershed to estimate the area that could be restored based on the cost associated with the identified action. The practitioners were reluctant to provide an area-based measure for restoration in relation to cost, as many variables influence the cost and subsequent area of a project, including permitting cost, location, ecosystem (e.g., shoreline, wetland, stream), restoration type (e.g., abiotic, biotic), project type (e.g., bank stabilization, wetland enhancement, in-stream restoration), distance to work site, price of materials (which are market-driven), availability of materials, engineering requirements and stream width/length.[lxiv] Furthermore, the proportion of abiotic and biotic projects — restoration types that would significantly impact the carbon benefit — was unclear. Finally, the identified action relied on a cost estimate that was grounded in doubling current funding under New Brunswick's Environmental Trust Fund (ETF). In theory, one approach would be to evaluate the area of restoration of previously funded projects, then double that. However, projects are rarely funded solely by the ETF. In many instances, organizations seek funding from multiple funding bodies to support projects. Consequently, the cost per project would not be representative of the true cost of restoring a given area.

Action: Regulate and enforce regulations on development of lakes occupied by Prototype Quillwort

Spatially explicit carbon storage estimates[lxv] were used to derive quantitative estimates of total carbon stock for Prototype Quillwort locations. Species occurrences were provided by the Atlantic Canada Conservation Data Centre,[lxvi] with point locations buffered by the uncertainty value (m^2). Total carbon storage within each buffered location was derived by overlaying buffered locations with spatially explicit carbon storage estimates.[lxvii] These estimates are considered conservative given that not all species locations have been identified and mapped. For instance, a federal Species at Risk Act management plan[lxviii] identifies six lakes within New Brunswick where Prototype Quillwort has been found, yet only three lakes were included within our analysis, as records prior to 1960 or with no date (n.d.) were removed. Moreover, the spatially explicit carbon maps are terrestrial-focused, and open-water land cover classes (e.g., lakes, rivers) were assigned carbon storage values of zero. Consequently, the carbon storage value is likely greater than reported here (0.05 Mt CO_2).

STRATEGY 16: CLIMATE CHANGE POLICIES AND ACTIONS

Action: Grow and maintain early flowering native plants

Due to a lack of publicly available emissions factors (a representative value that relates the amount of greenhouse gases associated with an activity) associated with the quantity/area of planting native flowers, alternative methods were employed. Specifically, an analysis was conducted to assess reasonable temporal carbon sequestration estimates for Canada. The scope of review included temperate areas, as the available studies for Canada were insufficient. Carbon sequestration rates were compiled from individual studies and average values produced for estimating carbon sequestration of flowering plants. Maximum values are reported here; they have not been discounted to reflect the potential for changes in survivorship, nor for the type of species (e.g., some annual plants have negligible carbon benefits).[lxix] Moreover, it should be noted that sequestration rates would vary considerably depending on the geographic location and local climatic profile for ecoregions within Canada. Emission factor proxies, based upon literature review, were 0.1t CO_2/ha/year for 10 years, and 0.2t CO_2/ha/year thereafter. The identified conservation action includes annual planting for 10 years, meaning there is a greater number of plants and total area contributing to the carbon estimate over time. Expert elicitation with practitioners in the region suggests that approximately 2,000 plants or 6,000m^2 (assumes a cost of $10/plant) could be planted annually (0.06t CO_2 total over 10 years) at a cost of $20,000 (plus $5,000 for equipment and labour). This model uses two volunteer events, one co-ordinator and two technicians to accomplish planting objectives. Integrating emissions factors with the linear growth in planting over 10 years results in a cumulative carbon sequestration estimate of 22.2 tonnes CO_2 by 2050.

Table S2. List of conservation strategies and actions identified through the Priority Threat Management analysis. Carbon benefits were those identified as being direct, quantifiable and with sufficient information to calculate. In some cases, two actions and/or strategies were needed to credibly report on the carbon benefit.[1] The ***** *denotes which actions were used to quantify carbon, while the* ***Y*** *denotes actions needed for implementation to achieve carbon benefits.*

STRATEGIES AND ACTIONS			CARBON
S1	Public land management		
	a	identify, prioritize and protect areas of public land that will contribute toward achieving Canada's Target 1 objectives (17 per cent of habitat area protected) and to structural and functional connectivity on the landscape	Y*
	b	identify and protect known occurrences of rare, restricted plants and lichen communities	Y*
	c	advance the identification of important (key) habitat for dragonflies, Cobblestone Tiger Beetles, monarchs and bumblebees (e.g., schedule of studies)	
	d	identify and protect bat maternity colonies and winter hibernacula; manage maternity sites	Y*
	e	research and identify hotspots for wildlife crossings (including for turtles and migratory fish) to guide planning decisions for road placement decisions, appropriate restrictions (e.g., speed restrictions) and infrastructure (e.g., crossings, culverts)	
S2	Forestry land management		
	a	determine distribution of wood turtles by (sub)watershed across the province	
	b	ensure that forest companies have the best available data on species occurrences	
	c	conduct research to support the determination of population- and distribution-based habitat objectives and inform the preferred related forestry management options	
S3	Private land management		
	a	develop integrated conservation plan for private land that takes an ecosystem-based approach: conduct research to understand habitat use and requirements of species of conservation concern in agricultural areas or anthropogenic structures; identify hotspots and develop best management practices (BMP) to minimize impact of agricultural activities; develop incentive programs to protect these species, restore degraded habitat, and promote implementation of BMPs	
	b	implement integrated conservation plan for private land: establish a central hub for information with a coordinator; implement outreach, stewardship and training/education program to inform landowners and general public and promote BMPs to conserve species of conservation concern on private land; implement citizen science programs to fill knowledge gaps on species location	
	c	capital investment in endowment fund for private land purchases for conservation (contributes to Target 1)	Y
S4	Wetland and aquatic habitat management		
	a	identify and map small forest wetlands/ephemeral water bodies and improve wetland policy for small wetlands (< 1 ha)	Y*
	b	mitigate impacts of priority culverts to ensure proper aquatic passage	
	c	conduct wetland, shoreline and stream restoration activities	Y*
S5	Dam discharge flow management for Mactaquac and other dams		
	a	optimize minimum maintenance flow by requiring minimum discharges to improve benthic invertebrate and fish productivity and maintain healthy river as best possible (six dams: Mactaquac, Beechwood, Tobique Narrows, Grand Falls, Tinker and Sisson)	
	b	improve fish passage through dams by installing or improving downstream collection and/or bypass for Mactaquac, Beechwood and Tinker dams, and improve operation (facility capacity) for Tobique Narrows Dam	

[1] For instance, protecting and conserving 17 per cent of New Brunswick's lands and freshwater is the action, but a capital investment fund represents *how* that target will be achieved. Similarly, mapping small wetlands is important, but actually implementing wetland policies for those areas will more effectively achieve conservation action.

STRATEGIES AND ACTIONS			CARBON
S6	Removal of Mactaquac Dam and discharge flow management for other dams		
	a	remove Mactaquac Dam and restore river flow (powerhouse, main spillway and diversion sluiceway and associated infrastructure removed; earthen dam decommissioned and removed)	
	b	optimize minimum maintenance flow by requiring minimum discharges for five other dams	
	c	improve fish passage by installing or improving downstream collection and/or bypass for Beechwood and Tinker dams, and improve facility capacity for Tobique Narrows Dam	
S7	Illegal and incidental take policy and regulation		
	a	increase enforcement and strategic surveillance of illegal collection of species of conservation concern	
	b	strategic and targeted public outreach and communication about poaching and accidental snaring	
S8	Wetland policy and regulation		
	a	implement public campaign around importance of protecting wetlands to increase support for changing wetland policy to provide protection for more wetlands (including small wetlands/wet forests)	
	b	implement new wetlands strategy on private land through provincial coordinators	Y
S9	Water quality management		
	a	monitor water quality	
	b	educate land-owners and developers, and regulate and enforce regulations on development on lakes occupied by Prototype Quillwort	Y*
	c	implement best management practices for incorporating green infrastructure for stormwater treatment into new development plans	
S10	Breeding, rearing and re-introduction of Atlantic Salmon and yellow lampmussel		
	a	develop and implement program for population augmentation of yellow lampmussel	
	b	improve facilities at Mactaquac Dam for salmon population enhancement	
S11	Disease management for bat species		
	a	conduct outreach and awareness activities to minimize transmission of white-nose syndrome and improve compliance with decontamination protocols	
S12	Forest pest management		
	a	conduct research to identify strains and understand virulence of butternut canker, the phylogenetics of NB population and the potential for hybridization with Japanese Walnut	
	b	conduct gap collection of butternut seeds for ex-situ conservation and seed banking	
	c	understand the genetic variation of Black Ash in NB and undertake a representative collection of seed	
	d	collect hemlock seeds for seed-banking and ex-situ conservation	
S13	Invasive species management		
	a	use social marketing to improve awareness of invasive species establishment and spread	
	b	enforce and promote compliance with policy and regulation for invasive species management	
	c	develop a provincial aquatic invasive species policy	
	d	develop and implement programs for monitoring and preventing the arrival or spread of aquatic and terrestrial invasive species	
	e	set up 10 cleaning stations for boats and other recreational vehicles	
	f	develop and promote best management practices for honeybee and commercial bee management to manage escapes and disease transmission	
	g	research impacts of non-native earthworms in forests	
	h	develop and implement provincial policy requiring the use of locally sourced native plants in site restorations	

STRATEGIES AND ACTIONS			CARBON
S14	Predator management		
	a	conduct research to understand the scope of the threat of cat predation and the impact on birds, focusing on rural communities and ongoing monitoring	
	b	implement/enforce cat licensing and tracking policies and free pet microchipping programs	
	c	control free-ranging cat population and provide funding to shelters for housing feral cats	
	d	conduct research to determine whether predation has an impact on turtle populations	
	e	conduct research to determine location of problem areas (high incidence of predation), and modelling study to predict locations of potential predation on turtle populations	
	f	identify problem areas and implement targeted program to promote better waste-management systems to reduce food subsidies to predators	
	g	trap and cull predators in problem areas	
	h	implement turtle nest protection program and use mesopredator deterrents to discourage nest predation at sites where other options are not feasible	
S15	Pollution reduction and management		
	a	determine if water quality thresholds are exceeded and modify and properly implement policy around management of pesticide/herbicide use if needed	
	b	implement a five-year education and buy-back program to incentivize hunters to switch to non-lead ammunition, and develop regulations to reduce use of lead bullets by hunters	
S16	Climate change policies and actions		
	a	maintain food availability for bees and other insects by providing early flowering plants through a provincial education program for increasing public awareness of and concern for bees, and of beneficial conservation actions on private property	Y*
	b	establish grant program for municipalities, communities and NGOs to grow and maintain early flowering native plants in gardens and conduct outreach activities	
	c	design and implement policy to foster/maintain early flowering plants on provincial land	
	d	identify and protect climate refugia for fish: map, prioritize and protect stretches of tributaries that are likely to act as cold-water climate refugia for juvenile/adult salmon	
	e	initiate a provincial program to support Regional Service Commissions, municipalities and local service districts in ensuring that land-use plans and watershed plans are forward thinking, climate-adapted and benefiting biodiversity	
S17	Land management across tenures		
		S1 + S2 + S3	
S18	Riparian, wetland and aquatic habitat management and policy		
		S4 + S5 + S8 + S9	
S19	Policy development and implementation		
		S7 + S8 + S15 + S16	
S20	Dam discharge flow management and population enhancement		
		S5 + S10	
S21	Land and predator management		
		S1 + S3 + S14	
S22	All strategies except removal of Mactaquac Dam and discharge flow management (S6)		
		S1 - S5, S7 - S16	
S23	All strategies except dam discharge flow management for Mactaquac and other dams (S5)		
		S1 - S4, S6 - S16	

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