Ecological Restoration: Nature-Based Solutions for Climate Mitigation and Engaging Canadians with Nature

Principal Investigator: Eric Higgs[1]
Co-Investigators: Steven Cooke[2], Stephen Murphy[4], Line Rochefort[3], Nancy Shackelford[1], Sarah Wilson[1]
Graduate Student Researchers: Tim Alamenciak[4], Sarah C. Bird[1], Claire Boismenu[3], Gwendal Breton[3], Stephanie Cruz Maysonet[2], Alina Fisher[1], John-Francis Lane[2], Dorian Pomezanski[4], Sonia Voicescu[1]

[1] University of Victoria | [2] Carleton University | [3] Université Laval | [4] University of Waterloo

June 30th, 2021

This report draws on research supported by the Tri-Council (Social Sciences and Humanities Research Council (SSHRC), Natural Sciences and Engineering Research Council (NSERC) and the Canadian Institutes of Health Research (CIHR)) through a Knowledge Synthesis Grant: *Living Within the Earth's Carrying Capacity* administered by SSHRC.

Photos (L-R): Atlantic salmon restoration (Nigel Fearon Photography for Parks Canada, adapted with permission); Peatland restoration (S. Hugron); Garry oak meadow restoration (Nancy Shackelford).

EXECUTIVE SUMMARY

Background:

Ecological restoration is an increasingly prominent practice to address urgent environmental challenges that threaten nature and the benefits humans derive from it. Canadians have played an outsized role in leading and developing the field of ecological restoration. Practically every type of restoration practice is represented in Canada, from large-scale tree planting to school yard rewilding, from long-term research restoration projects to pop-up urban restoration. Our focus was to complete the first comprehensive and systematic examination of ecological restoration in Canada. Much has been achieved, but how can we build on this accomplishment to make Canada an undisputed global leader in ecological restoration?

Objectives:

Our project was guided by two objectives: 1) Synthesize and critically assess the state of ecological restoration knowledge in Canada; and, 2) Identify and assess restoration policy (or policies related to restoration) in Canada.

Results:

- Canadian ecological restoration literature shows wide collaboration and variation in terms of approaches, but it is concentrated in a few locations, particularly where primary extractive resources occur (e.g. Alberta, Sudbury and Quebec). The variables used to measure the outcomes of restoration interventions varied widely, making it challenging to compare across projects. Although practitioners could access peer-reviewed literature, many lacked time to read it.
- Semi-structured interviews with restoration specialists revealed that Canadian ecological restoration is still emerging, and faces challenges such as lack of political will and financing. However, momentum for restoration action can be generated by raising public awareness of the practice and showcasing success stories to help connect people to nature locally.
- Early and continuous engagement of diverse stakeholders is perceived by practitioners as the most important factor in the ongoing restoration of Atlantic salmon at Fundy National Park.
- For almost 30 years (since 1992), the research team of the Peatland Ecology Research Group in collaboration with the Canadian peat industry has developed an efficient partnership, established two research stations (bog and fen) akin to the Long Term Ecological Research of National Science Foundation program, and developed a recognized approach to restore degraded peatlands.
- Funding mobilized for species-at-risk recovery facilitated the development of knowledge-sharing infrastructure that supports Garry oak ecosystem restoration, and community interest in an at-risk ecosystem has supplemented restoration funding with a long-term volunteer base.

Key messages:

- Restoration in Canada is collaborative, both in the co-production of knowledge and in the development and implementation of restoration projects. Funding structures and incentives should continue to promote collaborative restoration projects.
- Published academic literature is shifting towards climate change impacts and the potential of restoration to mitigate climate change impacts - this finding has a clear policy link for incorporating restoration as a climate change management tool in new climate policy.
- Several ecosystems are underrepresented in the literature: aquatic, arctic, and alpine ecosystems, and those facing intense pressure in urban environments. These should be the focus of new research, particularly because of the significant impact of climate change on aquatic, arctic, and alpine ecosystems.
- Management literature from government agencies, NGOs, or community groups is difficult to access, which presents challenges for researchers aiming to synthesize knowledge amassed at the community level and in private practice. Research efforts to identify structures and processes that would bridge the gap between practice and research would help mobilize that knowledge.

Methods:

Objective 1 was fulfilled using a systematic literature review method of "research weaving" to combine bibliometric analysis with a systematic evidence map; this yielded over 3000 relevant articles associated with ecological restoration in Canada. We expected that the literature review would miss almost all of the non-professional literature ("the grey literature"). We embarked on a series of cross-Canada practitioner interviews. Semi-structured interviews were conducted with restoration professionals, i.e. those with a minimum of five years of relevant professional experience with ecological restoration practice or policy in Canada. Our realized sample size was 69 interviews (response rate of 81%; participation rate of 87 %).

For Objective 2, the literature review and interviews were designed to give us early insight on any systematic analysis and personal experiences with policy analysis as they pertain to restoration. However, we knew that both sources were not founts of knowledge, e.g. the literature has only recently begun to include proper social science methods for policy analysis of restoration. To take a deeper dive into policy effectiveness, we used three case studies: Atlantic salmon recovery in Fundy National Park (single case with interviews of a major force in ecological restoration - Parks Canada), peatland restoration (a long-term industry driven research partnership for responsible management), and Garry oak ecosystem restoration (an endemic ecosystem with ample work done, hence grey literature reviews, professional literature reviews, and semi-structured interviews were completed).

1.0 BACKGROUND

There is evidence to suggest ecological restoration can be a cost-effective approach to mitigating problems even at the scale of global anthropogenic climate change. Locally, restoration has the potential to engage people. The act of restoration - in a schoolyard, a community stream cleanup, large-scale tree planting - engages people with nature. In an urbanizing and rapidly changing world it is exactly this kind of connection that holds promise for a profound change in how people relate to the other-than-human world.

The untimely combination of climate change, resource extraction, urbanization, invasive species, nitrogen deposition, microplastics and other drivers of change in land, freshwater, and marine ecosystems is causing an unprecedented collapse of some ecosystems (e.g., tundra), biodiversity losses and extinction in others, and the erosion of life-support capacities. An increasingly prominent remedy for these urgent challenges is ecological restoration. Ecological restoration embodies the aspiration of creating something positive and hopeful. It aims "to assist the recovery of ecosystems that have been degraded, damaged or destroyed." Superheating the still young (30 years) field of restoration is the urgency of finding nature-based solutions to urgent climate mitigation and poverty alleviation, which is a major focus of the recently-launched UN Decade on Ecosystem Restoration (2021-2030).

Canadians have played an outsized role in leading and developing the field of ecological restoration. Fourteen percent of the international Society for Ecological Restoration (SER) members are Canadian (the highest per capita in the world). Since 1989, 3 of 11 chairs of SER have been Canadian. Three major international conferences have been hosted in Canada. The Editor-in-Chief of the flagship journal Restoration Ecology, Stephen Murphy, is Canadian. Parks Canada and the Canadian Parks Council (2008) developed the first national level principles and guidelines for ecological restoration in the world. These guidelines formed the basis for the first global advice on restoration (Keenleyside et al. 2012). The list goes on. Practically every type of restoration practice is represented in Canada, from large-scale tree planting to school yard rewilding, from long-term research restoration projects to pop-up urban restoration.

With restoration happening everywhere and at many scales, what gaps exist and how can these be filled? The focus of our research project was to complete the first comprehensive and systematic examination of ecological restoration in Canada. Much has been achieved, but how can we build on this accomplishment to make Canada an undisputed global leader in ecological restoration?

2.0 OBJECTIVES

Our project was guided by two objectives: 1) Synthesize and critically assess the state of ecological restoration knowledge in Canada. What gaps exist, and how can these be filled? What opportunities are presently unmet? What are the elements of a comprehensive research agenda for ecological restoration for the next decade? 2) Identify and assess restoration policy in Canada. What opportunities are there for increasing nature-based solutions through effective policy? What current policy instruments seem to be working? Where could policies be strengthened, modified, or implemented to encourage restoration efforts?

We addressed the two objectives through three distinct methods: 1) strategic literature review of Canadian restoration science and practice; 2) semi-structured interviews with restoration specialists; and 3) three case studies - Atlantic salmon recovery in Fundy National Park, peatland restoration, and Garry oak ecosystem restoration.

The strategic literature review systematically analyzed the published research on Canadian ecological restoration. Despite the significant contributions of Canadian restoration ecologists in developing restoration as a discipline, relatively little is known about characteristics of restoration in Canada. Such syntheses have potential to provide insights for policymaking and research directions for restoration ecology more broadly.

Interviews with practitioners took the form of semi-structured interviews with restoration professionals in Canada aiming to assess the state of restoration practice and policy. The goals of these interviews were to elicit knowledge on: 1) restoration work that is currently underway in Canada, 2) current resources and gaps faced by practitioners, and 3) perceptions of best practices and opportunities.

Each of the three case studies had different approaches to identify strengths and opportunities within each type of restoration work. The case study on Atlantic salmon recovery had three objectives: 1) describe the components of an ecological restoration project implemented by the Parks Canada Agency; 2) discuss the effectiveness of applicable ecological restoration policies based on the perceptions of practitioners; 3) identify challenges and opportunities for improvement in ecological restoration practice and policy. The peatland restoration case study focused on examining the history of peatland restoration in Canada. Within the Garry oak ecosystem case study the focus was a broad survey of ongoing restoration projects

3.0 METHODS

3.1 Literature Review

In order to gain a thorough understanding of the Canadian literature on ecological restoration, we adopted a hybrid literature review methodology known as “research weaving” (Nakagawa et al., 2019). This methodology combines a bibliometric analysis with a systematic evidence map to analyze both the processes of knowledge generation (e.g. key researchers, institutions and subject areas) and the contents of the body of knowledge (e.g. ecosystem types, disturbance types, etc.). This methodology necessitated two distinct search strategies with some shared characteristics.

Phase 1: Bibliometric analysis

First, we considered research to be Canadian if it took place in Canada or was done by a researcher affiliated with a Canadian institution. For the purposes of the systematic evidence map, our search criteria focused exclusively on studies conducted in Canada in order to synthesize the body of knowledge about Canadian ecosystems. We conducted our initial literature searches in Scopus and Web of Science using a search string developed in collaboration with a University of Waterloo research librarian. Our search was limited to Scopus and Web of Science for the bibliometric analysis because of the limitations of the R package, Bibliometrix.

Truncated sample from Scopus search (full search included country and province terms):

> TITLE-ABS-KEY("restoration ecology" OR "eco* restoration" OR "environment* restoration" OR "habitat restoration" OR "eco* remediation" OR "environment* remediation" OR "habitat remediation" OR "eco* reclamation" OR "environment* reclamation" OR "habitat reclamation" OR "eco* rehabilitation" OR "environment* rehabilitation" OR "habitat rehabilitation" OR "rewild*" OR "re-wild*" OR "reforest*" OR "re-forest*")

The search above returned 4,014 results from the Scopus database. An identical search on ISI's Web of Science (WOS) returned 230 additional records. The structure of the two databases is different, which prevented directly merging the two, so Scopus was used because it contained more results. The Scopus entries were manually screened for relevance. Screening involved reading through Scopus-extracted meta-data such as title, abstract, author affiliations, keywords, and journal. Scopus indexes journals that contain French-language articles, but includes their English-language abstract. Our search captured 28 French-language articles and 10 met our screening criteria.

Following the creation of screening criteria, 400 entries were screened independently by the two reviewers and the decisions compared to calculate Cohen's Kappa, which is a measure of inter-rater reliability that factors in random agreement. The overall agreement between the two reviewers was 85 per cent. Cohen's Kappa for the set was 0.496, which indicates a moderate level of agreement. A higher value would be ideal, however due to time constraints the reviewers elected to proceed with the screening after a thorough discussion of the reasons for rejection. All screening decisions were documented. The entries that remained after initial screening (n = 3,013) were analyzed using the Bibliometrix R package (Aria & Cuccurullo, 2017).

Phase 2: Systematic Map

We expanded our literature search to include additional academic literature databases and grey literature databases for the systematic map, but modified the search terms to constrain the results to those that included outcomes of ecological interventions. The following databases were searched: Scopus, Web of Science, ScienceDirect, Google Scholar (first 500 results), two major journals (Ecological Management and Restoration and Ecological Restoration), the Federal Science Library of Canada, ProQuest Canadian Research Index, GEOSCAN, Aurora, ProQuest Dissertations and Theses Global and NRC Publications Archive.

Since each database had different advanced search options, formats, and limits, we altered the search strings appropriately to fit each database's limitations. The search string for Scopus was the most comprehensive and served as a model for the remaining searches. We filtered results based on their inclusion of the terms "BACI", "recover", "outcome", "success", or "failure" in the title, abstract, or keywords to focus on studies that documented outcomes of ecological interventions. Some search options in other databases were limited in maximum length or search capacity so alterations were made accordingly.

Our literature search returned 2,357 entries in total after removing duplicates. Screening and data extraction were performed in Cadima, an online tool for systematic reviews. Screening took place in two stages: title and abstract, followed by full-text screening. We had two primary screening criteria: 1) Is the research site in Canada?, and 2) does it include field research that measures outcomes of intentional ecological interventions by humans? We performed a consistency check wherein each reviewer screened 10 % of the set (n = 235). The resulting Cohen's Kappa score was 0.339 which indicated "poor" agreement. However, the material agreement was quite high. We disagreed on only 13% of records in such a way as the inclusion would be affected and of those 30 disagreements, nearly half (n = 14) were a result of one reviewer selecting "unclear" for one of the criteria. We discussed each material disagreement to reach clarity on our application of the inclusion criteria. The second step of the screening process involved full-text screening using the same criteria. The full-text screening resulted in 308 appropriate literature entries for data extraction.

Data extraction

We performed a manual extraction of data in 16 fields. Those fields were: first author affiliation, action taken, intervention type, coarse ecosystem type, fine ecosystem type, main species, disturbance type, reason for restoration, reference ecosystem type, research province, research city, research coordinates, time since restoration, monitoring period, outcome sentence and response variables. In six cases the data produced results that were too heterogenous for meaningful analysis, so an additional layer of coding was applied to the extracted data to group results (Table 1).

Table 1: Aggregate extraction categories

Original field	New field	Categories
First author affiliation	Aggregate affiliation	Provincial government, Federal government, Academic, NGO
Fine ecosystem type	Aggregate ecosystem type	Alpine, Anthropogenic, Boreal forest, Coastal, Forest, Freshwater, Grassland, Marine, Peatland, Riparian, Savannah, Tundra
Main species	Coarse target species group	Animals, Fungi, Lichen, Plants
Main species	Fine target species group	Aquatic, Birds, Fish, Invertebrates, Herbaceous, Non-vascular, Woody, Herptiles, Mammals
Disturbance type	Coarse disturbance type	Agriculture, Anthropogenic habitat alteration, Biotic pressure, Climate change, Energy, Fire, Forestry, Industrial, Invasive species, Mining, Overexploitation, Peat extraction
Response variables	Coarse response variables	Plant responses, animal responses, soil responses, microbial responses, abiotic chemical responses, hydrological responses, land responses, diversity responses

3.2 Practitioner Interviews

Participant selection and recruitment

Semi-structured interviews were conducted with restoration professionals between October and December 2020. Participants were aged over 18 years and were selected based on a minimum of five years of relevant professional experience with ecological restoration practice or policy in Canada. Participants were recruited via publicly available contact information, from online government databases and company websites. In certain cases, recruitment involved directed sampling, and was based on trusting relationships between the project proponents and members of local organizations, as well as federal and provincial governments. Snowball sampling was also employed with potential participants to recruit additional interviewees.

Participant selection aimed to be representative of geographic location and employment sectors within the field of ecological restoration. A total of 97 invitations to participate in the study were sent out. Of those, 79 responses and 69 confirmations to participate were received, resulting in a response rate of 81% and a participation rate of 87 % (AAPOR, 2016). Informed consent was obtained from all participants included in this project and all procedures performed in this study were in accordance with the ethical standards of the University of Victoria Human Research Ethics Board (approved protocol number 20-0398).

Interview structure

The interview process consisted in a pre-interview questionnaire for demographic data collection, along with the main interview itself containing 14 questions divided into four themes. These themes were designed to address both policy and practice aspects of the discipline. The interviews lasted approximately 60 minutes per participant and were conducted in both English and French to account for linguistic preferences within different provinces. All interviews were conducted remotely.

Data analysis

Once interviews were complete, recordings were imported into the Otter.Ai transcription software and manually corrected for accuracy. Corrected transcripts were then imported into the ATLAS.ti program for content analysis. At this stage of the project, only one question (Question 3) has been fully analyzed using content analysis methods. Responses from all other questions have been summarized, and full content analysis is pending.

For Question 3, a coding scheme was developed based on a combination of deductive and inductive approaches (Elo & Kyngäs, 2007). This method was chosen to account for the researchers' knowledge of the research topic and question to be analyzed, while also allowing for themes to emerge from the transcripts themselves. Transcripts were segmented into data units in a conceptual manner, which allowed for individual lines or sentences to be grouped together based on their overall narrative and the cohesiveness of proposed ideas (O'Conner & Joffe, 2020). Coding was performed until data saturation, when themes were fully developed and no new codes would emerge (Corbin & Strauss, 2008; Fusch & Ness, 2015). A hierarchical coding frame (Fig.1) was adopted to organize the codes based on their relationship to one another and facilitate the development of a thematic narrative.

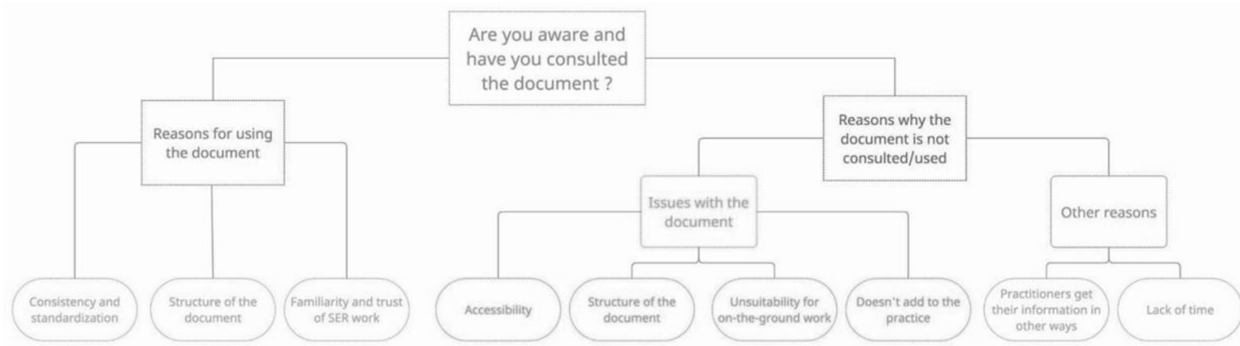

Fig. 1: *Hierarchical coding scheme developed to analyze participants' responses from interview Question 3 (awareness and use of the Society for Ecological Restoration's International Principles and Standards for the Practice of Ecological Restoration).*

Intercoder reliability (ICR) was performed by two coders on a sample of Question 3 interview transcripts (15%, n=11). The sample data was selected to be representative of both geographic location and participant occupation. ICR was assessed using Krippendorff's alpha test (Hayes & Krippendorff, 2007), and was determined to be relatively high ($\alpha = 0.8805$).

3.3 Case Studies

3.3.1 Atlantic Salmon Restoration

A single case study approach was used based on interviews and document analysis. Semi-structured, one-on-one online interviews with three key individuals were conducted in January and February 2021. Participants were Fundy National Park employees that held or had held administrative or managerial roles in relation to the restoration project. Recruitment was done with assistance of a Parks Canada Agency employee at the Conservation and Restoration Program who invited eligible participants, and through referrals from participants (i.e., snowball sampling). Interviews were video recorded, and an initial automatic transcription was generated using the live caption function in Microsoft Teams (Version 1.4.00.4167). Transcripts were manually edited afterwards for accuracy. Transcripts were de-identified and each participant received a unique alias.

Publicly available documents about the restoration project were reviewed including official reports, planning documents, and magazine and newspaper articles identified from project partners' websites. Additional information on the recovery project was gathered from the content of project partners' websites and from internal reports (a) identified as relevant by participants and (b) provided by them. Relevant academic publications were obtained from the databases Scopus and Web of Science after a two-step review process of 39 unique publications for the combined search terms "Fundy National Park" and "salmon". Only three publications were included in the analysis.

Interview responses and document information were initially coded with respect to six main themes: project partners, reasons for restoration, restoration methods, monitoring activities, policies, and challenges/opportunities. Additional codes were developed inductively around project components and participants' perceptions of policy effectiveness and project challenges, gaps, and opportunities. All coding was done manually. A complete draft of the study findings was shared with each participant for a chance to make corrections or reconsider anything said. This study received ethics approval from the University of Waterloo Office of Research Ethics (ORE #42723).

3.3.2 Peatland Restoration

The peatland restoration case study involved a literature review of over 180 scientific articles, over 50 publications in conference and workshop proceedings, 11 books, 22 book chapters, at least 24 reports and 14 magazine-type articles. These are the publications resulting from the research work of the Peatland Ecology Research Group (PERG) researchers, graduate students, postdoctoral fellows and research professionals from 1992 to 2021.

3.3.3 Garry Oak Ecosystem Restoration

The Garry oak ecosystem restoration case study collected information from a grey literature search, semi-structured interviews, and an academic literature search. Grey literature was accessed from a diversity of sources: online searches for public reports, searches of available resources on the Garry Oak Ecosystems Recovery Team (GOERT) website and the Cascadia Prairie Oak Partnership (CPOP) website's Technical Library to identify specific restoration projects, and e-mail communication with restoration practitioners to access unpublished grey literature. Where project information was unpublished, some semi-structured phone conversations with practitioners (University of Victoria Ethics Approval #20-0425) were used to find out about restoration methodologies for specific projects. Finally, a search using the SCOPUS database and the search string: TITLE-ABS-KEY-AUTH ((Canada OR "British Columbia" OR "BC" or "B.C.") AND ("garry oak" OR "quercus garryana") was used to identify existing academic literature on Garry oak ecosystems in Canada (either Canadian locations, or Canadian researchers involved with the project). Between the SCOPUS search and other literature collected throughout the project, a total of 65 papers relating to Garry oak ecosystems in Canada were located.

A total of 102 restoration projects in Canadian Garry oak ecosystems were included in a map, and project information for 41 of the projects were used in the analysis based on the projects for which information became available during the case study. Information on 16 projects came from supplied or publicly available reports, with another 12 from reports by the Restoration of Natural Systems program at the University of Victoria, 11 from semi-structured interviews with practitioners, and the remaining two included information from personal observations. Projects were assessed to identify themes in the types of restoration interventions, volunteer contributions to the project, organizations and agencies involved in managing the restoration project, and the type of monitoring used. Papers were used to identify institutions, authors, and publications relating to Canadian Garry oak ecosystem restoration.

4.0 RESULTS

4.1 Literature Review

Bibliometric Analysis

The bibliometric analysis used 3,006 articles from Scopus. The results included articles published between 1961 to 2020 and originating from 715 different sources. Eighty-seven percent of the entries in the database consisted of peer-reviewed journal articles (n = 2,616). The number of published articles relating to ecological restoration rose steadily from 1961 to 2020.

Conceptual Structure

A keyword co-occurrence cluster network analysis revealed a lack of intensive isolation suggesting that despite our body of literature including several separate distinct research areas (e.g. forestry, peatland restoration), many ideas and concepts were shared among them. There were also some distanced keywords or keyword clusters including "natural regeneration", "wetland restoration" and "ecosystem restoration" suggesting either niche/specialized restoration terminologies or research areas with notable differences from extractive industry led restoration.

Fig. 2 illustrates the evolution of keywords over three time periods: 1961 – 2005, 2006 – 2012, and 2013 – 2020. These time periods were sliced in such a way that each time period included a similar number of literature entries. The first slice includes a wide variety of keywords that point to specific geographic locations (e.g. British Columbia) or specific extractive industries (e.g. reforestation, fisheries). Climate change emerged as a major theme in the second time period and further increased in prominence in the third time period. Some terminology varied over time, particularly with keywords such as "ecosystem restoration", "restoration", and "ecological restoration" which may be used interchangeably.

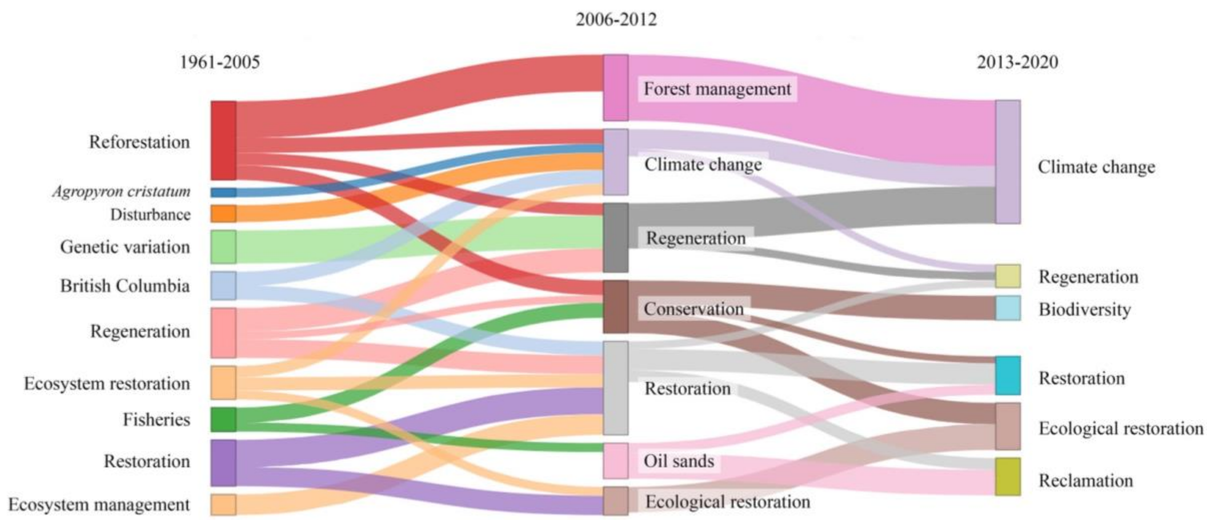

Fig. 2: *Thematic evolution of keywords over three time periods: 1961-2005, 2006-2012, and 2013-2020.*

Country collaboration analyses identified the USA and China as the countries that collaborated with Canadian researchers or institutions most frequently. Overall, three collaboration clusters were identified by the network clustering algorithm. The largest of these clusters included Canada, the USA, and China, along with other major Asian nations such as India, Japan, and Korea. A second collaboration cluster was focused exclusively in Europe and included major European nations such as Germany, France, Italy, Sweden, and Spain. The final cluster was the most geographically spread out and included nations from six separate continents. The institutional collaboration cluster network analysis identified more than a few close institutional relationships that were likely reflective of close research interests (for example peatland restoration in the case of the Laval University and McGill University collaboration cluster) or close collaboration between frequently-published researchers (e.g. Eric Higgs at the University of Victoria and Richard Hobbs at the University of Western Australia).

Systematic evidence map

The systematic mapping analysis included 308 pieces of restoration literature with field-based restoration occurring at least once in each province and territory. There was a clear concentration of entries in Alberta (n = 78), Ontario (n = 74), and Quebec (n = 69), which together accounted for about 68% of all entries (Fig. 3). Atlantic provinces were only modestly represented with 34 entries and the territories accounted for 6 entries in total.

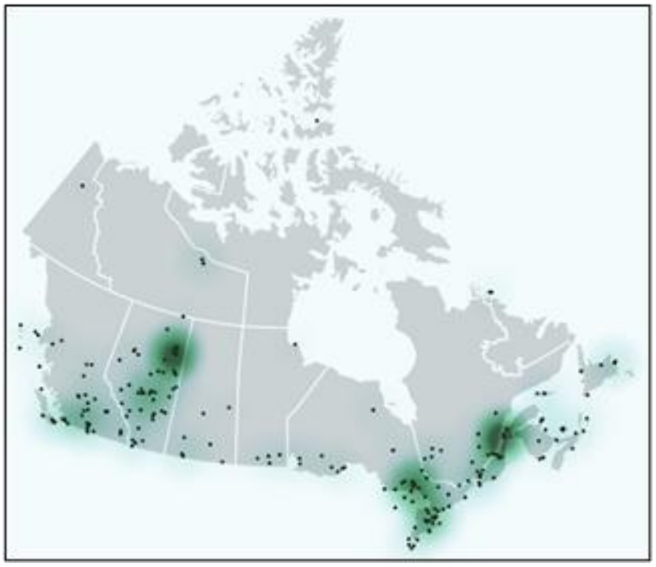

Fig. 3: *Distribution and concentration of restoration efforts identified in 308 entries included in the systematic mapping analysis*

Articles authored primarily by individuals affiliated with academic institutions made up the bulk of the entries in the systematic mapping body of literature, accounting for about 80% of all entries. The remaining entries were categorized most frequently as documents primarily authored by individuals affiliated with the federal government (n= 21), provincial government (n = 18), private organizations (n = 15) and NGOs (n = 6).

About 62% (n = 190) of the entries focused on terrestrial ecosystem restoration. Another 67 entries focused on transitional ecosystems such as peatland wetlands. Aquatic ecosystem focused entries (n = 51) were concentrated mainly in Ontario which accounted for over half of all aquatic ecosystem centered literature. Entries from Alberta focused heavily on forest ecosystems, with a lower number of entries addressing wetland and grassland restoration. In Ontario, forest and freshwater ecosystems were the dominant ecosystems represented in literature, while in Quebec, wetlands (primarily peatlands) featured heavily. Restoration literature in British Columbia was less focused and covered ecological restoration in a range of ecosystem types.

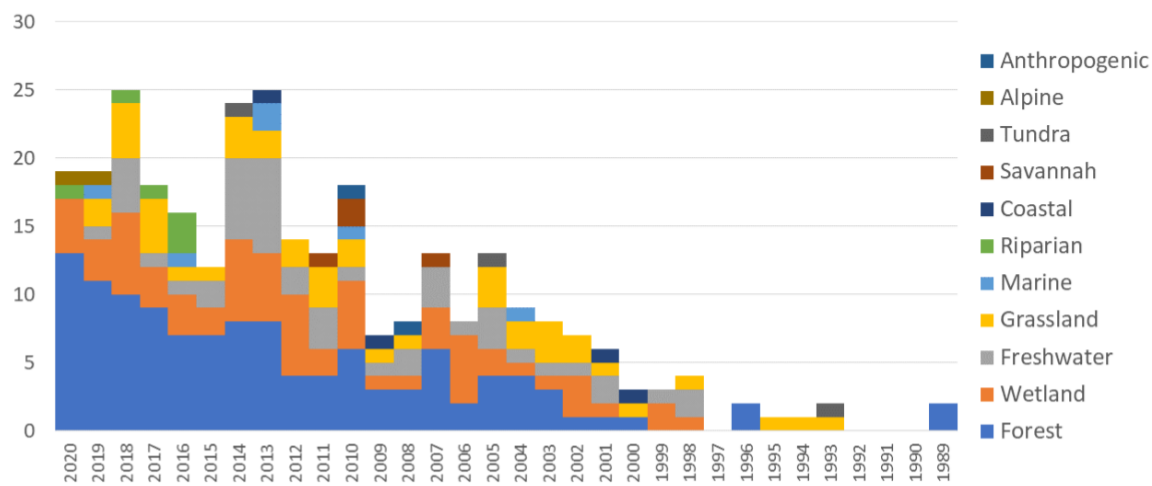

Fig. 4: *Ecosystem types featured in literature included in the systematic mapping analysis over time.*

The number of studies per year has been increasing since 1989. For the most part, the number of entries addressing the most common ecosystem types of forest and wetland increased over time (Fig. 4). In some cases, however, peaks in ecological restoration literature occurred in previous years, such as freshwater restoration literature in 2013/2014. Marine, alpine, and riparian ecological restoration literature have only recently emerged compared to restoration literature in grassland, freshwater, forest, and peatlands/wetlands.

The type of disturbances where most ecological restoration research was carried out were from natural resource extractions such as energy, forestry and peat extraction but the most widely recorded ecosystem upon which research effort was done was agriculture. Restoration research efforts following peat extraction were most frequently documented in Quebec while oil sands ecological restoration research was almost exclusively reported in Alberta. Agricultural ecological restoration was the most evenly distributed research across provinces. Industrial restoration was most reported in Ontario. The type of research on restoration ecology was more varied in Ontario and British Columbia in contrast to Alberta and Quebec, which were dominated by research on the restoration of forests and wetlands impacted by oil fields and the restoration of peat-extracted peatlands. All four entries addressing restoration research in the Northwest territories were related to mining disturbances.

Logical patterns emerged in the interaction between restoration of disturbance type being researched and target species being studied (Fig. 5). Ecological research in forestry mainly studied the reestablishment of woody plant species, peatland restoration non-vascular species (e.g. mosses and lichens), and agro-ecosystem restoration targeted more woody and herbaceous species. Mammal restoration/management was most often pursued in instances of overexploitation (e.g. excessive hunting or fishing). Anthropogenic habitat alteration induced by urbanization and associated urban structures (e.g. roads, dams, recreation) disturbances resulted in restoration focused on a variety of species groups including herbaceous plants, herptiles, and fish. Fish were also targeted in instances of overexploitation and industrial disturbance.

Active - biotic interventions such as reintroduction of wildlife populations and planting of native vegetation were widely applied to all disturbance types, occurring most frequently in peatland and agriculture restoration (Fig. 6). Passive restoration approaches which in general allowed disturbed sites to regenerate or rehabilitate by removing disturbances were most commonly applied in instances of peatland, forestry, and industrial ecological research. Active - abiotic physical restoration interventions such as pond creation, prescribed fire, and soil remediation were most commonly experimentally tested with the restoration of ecosystems impacted by energy based disturbances (e.g. oil sands extraction, seismic lines, pipelines), anthropogenic habitat alteration, peat extraction, and agricultural disturbances. Active - abiotic chemical approaches such as pesticide application were applied most often in the restoration of grassland ecosystems.

	Woody	Herbaceous	Non-vascular	Birds	Mammals	Herptiles	Invertebrates	Fish
Forestry	29	3	1	1	2	0	0	0
Energy	25	15	4	1	3	0	0	1
Mining	9	6	1	1	1	0	2	0
Peat extraction	10	11	37	1	0	0	0	0
Agriculture	19	20	0	3	3	2	0	1
Biotic pressure	4	1	0	1	0	0	0	1
Overexploitation	0	0	0	0	8	0	0	8
Fire	8	2	0	0	0	0	0	0
Anthropogenic habitat alteration	4	8	0	1	0	2	2	9
Climate change	1	0	0	0	0	0	0	0
Invasive species	2	15	0	1	0	0	1	0
Industrial	4	2	0	0	0	0	3	4

Fig. 5: *Heatmap illustrating the co-occurrence of disturbance types and coarse target species*

	Peat extraction	Agriculture	Energy	Forestry	Overexploitation	Invasive species	Mining	Anthropogenic habitat alteration	Biotic pressure	Industrial	Fire	Climate change
Active - biotic	32	30	24	19	16	16	13	8	7	6	3	1
Active - abiotic physical	17	17	23	9	1	5	9	15	1	2	6	0
Active - abiotic chemical	3	3	4	4	0	4	2	1	0	9	1	0
Passive	8	5	4	8	0	0	1	4	0	10	0	0

Fig. 6: *Heatmap illustrating the co-occurrence of intervention types and disturbance types*

Plotting the co-occurrence of target species groups (i.e. the species or species group for which the restoration was conducted) revealed that multiple plant species groups were frequently targeted in the same piece of restoration literature, but that there was not a single case of a study targeting both animal and plant species restoration concurrently. Co-occurrence of herbaceous, woody, and non-vascular plants as target species was common in peatland restoration efforts wherein entire plant communities were targeted for restoration.

We found evidence of frequent usage of multiple plant response variables, but low co-occurrence of plant response variables with microbial, abiotic chemical, and hydrological properties (Fig.7). Soil properties were often measured alongside plant response variables. Biodiversity responses of both plants and animals were used frequently although rarely concurrently.

Most ecological restoration efforts reported in our collection of entries were monitored for a period of <1 year to 5 years. These short-term monitoring periods were commonly applied in forest, and grassland ecosystems. They were also the most frequent monitoring periods in wetland and freshwater ecosystems. Longer term monitoring periods (5+ years) were more common in forest and freshwater ecosystems. No entries addressing coastal, savannah, tundra, and anthropogenic ecosystems monitored for longer than five years.

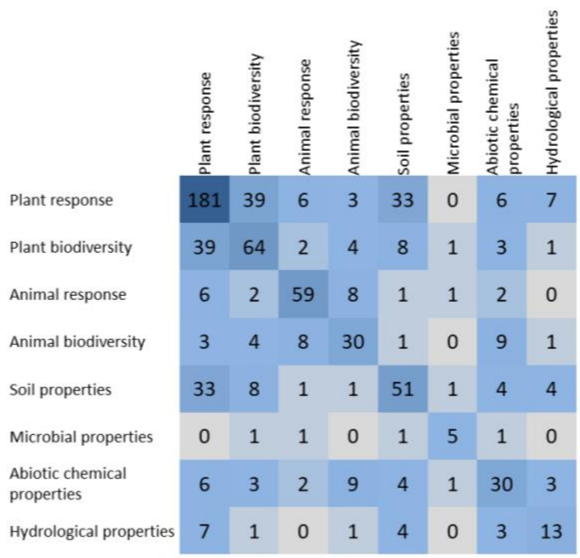

Fig. 7: *Heatmap illustrating the co-occurrence coarse response variables*

Research strengths and gaps

The strength of the bibliometric and systematic mapping analyses conducted here lie in their ability to effectively map out the interactions, relationships, and collaborations among institutions, countries, and researchers around the world. Identifying these relationships is an integral part of understanding how and where ecological restoration knowledge is being generated, and what part Canada is playing in that process. These analyses have also allowed us to illustrate the progression of themes and ideas over more than 50 years of published ecological restoration literature which can be used to identify the trajectory of future research and the roots of ecological restoration research in Canada. The detailed systematic mapping analysis component provided valuable hints of the nature and distribution of ecological restoration research which are important for the identification of research gaps, methodological shortcomings, and the adequacy of research representation across provinces/territories, ecosystems, and industries.

The most notable shortcoming of this analysis was the inability to efficiently search for, gather, and include a variety of grey ecological restoration literature. The absence of these documents underrepresents restoration efforts that tend not to publish results in a formal academic journal. Valuable information regarding outcomes, methods, and engagement are therefore lost in favour of details derived from prolific industry-led published literature. The inability to reliably extract restoration motivations or outcomes from the entries examined in the systematic mapping analysis weakened our ability to examine important information relating to incentives, drivers, and methodological success in the ecological restoration domain. This was compounded by the challenges of finding indexed publications in French.

4.2 Practitioner Interviews

The following sections will present preliminary results from a selection of interview questions responses. We present selected questions that directly address project goals.

Participants profiles

A total of 69 participants (31 males, 38 females) were interviewed from nine provinces and two territories. A considerable number of interviewees originated from Western Canada, in particular British Columbia (n=24, 34.8%). Most of the participants worked in three sectors: Environmental Non-Governmental Organizations (ENGOs) (n=26, 37.7%), government (n=22, 31.9%), and private industry (n=16, 23.2%). Common roles they occupied within their respective organizations were focused on program management, direction and supervision, and fieldwork. Participants were highly educated and quite experienced: a majority had obtained a master’s degree (n=36, 52.2%) and on average had been working in the field of ecological restoration for 17 years (SD=11 years). However, most interviewees had not completed specialized training in ecological restoration and did not belong to any ecological restoration society prior to participating in the interview. Complete demographic information collected from the participants can be found in Table 2.

Question 1

The first question of the interview asked, “What are the first three words that come to mind when thinking about the state of ecological restoration practice in Canada?”. Although responses varied with 167 different word responses, some common words or themes did emerge from this question. The most common responses included: emerging (n = 13); challenging (n = 12); evolving (n = 7); expensive (n = 7); and underfunded (n = 7). Interviewee responses were fed into a free online word cloud program (www.wordclouds.com) to generate a weighted word cloud of the 30 most common words (Fig. 8). The fact that “emerging” was the most cited word is an interesting outcome; it is a word that contains both positive and negative connotations, while overall highlighting that the restoration field is still new in Canada and has room to grow and adapt to future challenges.

Table 2. Aggregated demographic variables of interview participants (n=69).

Demographic variable	Frequency	Percentage (%)
Province		
Alberta	9	13.0
British Columbia	24	34.8
Manitoba	2	2.9
New Brunswick	3	4.3
Nova Scotia	2	2.9
Northwest Territories	1	1.4
Ontario	8	11.6
Prince Edward Island	2	2.9
Quebec	12	17.4
Saskatchewan	5	7.2
Yukon	1	1.4
Sector of employment		
Academia	3	4.3
ENGO[a]	26	37.7
Government[b]	22	31.9
International	1	1.4
Parapublic[c]	1	1.4
Private industry	16	23.2
Sex		
Male	31	44.9
Female	38	55.1
Role within organization		
Communications	4	5.8
Direction and supervision	13	18.8
Field/technical	11	15.9
Policy/regulations	6	8.7
Program management	22	31.9
Project planning	8	11.6
Research and education	5	7.2
Highest level of education		
No formal training	1	1.4
College/Cégep diploma	3	4.3
Bachelor	17	24.6
Master	36	52.2
Doctoral	12	17.4
Specialized ER training[d]		
Yes	16	23.2
No	53	76.8
Years of experience working in ER		
<10	18	26.1
[10-20)	23	33.3
[20-30)	20	29.0
[30-40)	3	4.3
≥ 40	5	7.2
Number of ER societies participants belong to[e]		
0	39	56.5
1	8	11.6
2	11	15.9
3	7	10.1
4	3	4.3
6	1	1.4

Notes: [a] Environmental non-governmental organizations; [b] Includes participants working at regional, municipal, provincial and federal government levels; [c] An organization partially funded by the government while maintaining a level of management similar to the private sector; [d] Refers to training specifically focused on ecological restoration; [e] Denotes membership to a society or group focused on ecological restoration work.

Fig. 8: *Word cloud, generated using www.wordclouds.com, of the 30 most common words (including synonyms) ecosystem practitioners provided when asked "What are the three words that come to mind when you think of the state of ecological restoration in Canada?"*

Question 2 & 11

Questions 2 and 11 asked: "What are the main tools (frameworks, guidelines, or policies) you use to guide your restoration activities / policy development?", and "Can you provide some examples of policies or guidelines that have enabled successful restoration projects?", respectively. From these two questions, we compiled the most commonly mentioned frameworks and guidelines (Table 3), and policies (Table 4). A total of 97 different frameworks, guidelines, and other tools were mentioned by interviewees. Responses ranged from gray and academic literature to local guidebooks on specific ecotypes or restoration techniques, to international guidelines, principles, and best practices.

Table 3 – The six most common frameworks or guidelines provided by interviewees when asked; "What are the main tools (frameworks, guidelines, or policies) you use to guide your restoration activities / policy development?"

Frameworks and Guidelines	**Publisher**
International Principles & Standards for the Practice of Ecological Restoration	Society for Ecological Restoration
Principles and Guidelines for Ecological Restoration in Canada's Protected Natural Areas	Parks Canada and The Canadian Parks Council
Ecological restoration for protected areas: principles, guidelines, and best practices	International Union for Conservation of Nature (IUCN)
The Open Standards for the Practice of Conservation	Conservation Standards
The Plant Conservation Alliance	Plant Conservation Alliance
The SER International Primer on Ecological Restoration	Society for Ecological Restoration

Similarly, a wide variety of policies, legislations, and government programs, from four different levels of governance (municipal, provincial, federal, and international), were mentioned in response to these two questions. Although the majority of responses to this question were provincial in jurisdiction (54.8%), followed by federal (22.6%), municipal (21.0%) and international (1.6%), the most commonly mentioned policies that enabled successful restoration were federal laws (Table 4).

Table 4 – The five most common policies provided by interviewees when askes; "Can you provide some examples of policies or guidelines that have enabled successful restoration projects?".

Policy	**Jurisdiction**	**Frequency**
Species at Risk Act	Federal	8
Fisheries Act	Federal	6
Environmental / Impact Assessment Act	Federal	6
Conservation Authority Act	Provincial (Ontario)	5
Various Municipal bylaws, policies, and strategic planning	Municipal	5

Question 3

The third interview question asked participants if they were aware of the Society for Ecological Restoration's (SER) International Principles and Standards for the Practice of Ecological Restoration document (Gann et al., 2019), and if yes, had they consulted it since its publication in 2019. A majority of respondents replied that they were aware of the publication (n= 39, 56.5%). However, when asked if they had consulted it, only about a third of all participants responded affirmatively (n= 26, 37.7%). After they answered the question, interviewees were given the opportunity to elaborate and comment on the relevance of the publication to their own practice and work in ecological restoration. Those responses were first coded into themes and subthemes, and code frequency was calculated for each of them (Table 5).

Participants who had consulted and were actively using the document mentioned that they liked it due to the level of consistency and standardization it provided. With the practice evolving rapidly, and new concepts and terminology being added frequently, the publication served as a reference source against which proposals could be evaluated. Some interviewees found the document to be realistic and appreciated the level of detail and resources provided. Finally, some participants embraced it because they trusted the work produced by SER, had confidence in the fact that it was reviewed by worldwide experts, and felt that the proposed principles harmonized well with each other.

However, based on content analysis, a majority of restoration professionals did not find the document useful and were not engaging with it. One of the top reasons mentioned revolved around accessibility. In this sense, many worried that the publication was very North American centered, and that it would appeal mostly to people in wealthy Western countries. This also brought forth issues with expertise bias, where many participants felt that the publication was mostly accessible to professionals that already had a background and a lot of experience in this field, whereas a lot of people that actually participate in restoration work, such as volunteers and students, do not have this experience. Those participants reflected that a common vision for restoration should include volunteers and community members, who end up doing a lot of the practical work. Some practitioners did not like the structure and format of the publication: they found it too long, too broad, and too complicated, with some even reflecting that they preferred the format of the previous SER primer (SER, 2004). Participants also found the publication not very suitable for on-the-ground work, and didn't find that it necessarily added to the practice. In this sense, they found that most of what was presented was common sense and somewhat repetitive to existing guidelines and documents.

Table 5. Code frequency for participants' awareness, consultation, and perception of SER document[a]

Code	Frequency	Percentage (%)
Awareness and consultation (n=69)		
Aware and consulted	26	37.7
Aware but not consulted	13	18.8
Not aware and not consulted	30	43.5
Reasons for using the document (n=34)		
Consistency and standardization	23	67.6
Structure of the document	7	20.6
Familiarity and trust of SER work		11.8
Reasons the document is not consulted/used (n=123)		
Issues with the document		
Accessibility	21	17.1
Structure of the document	17	13.8
Unsuitable for on-the-ground work	12	9.8
Doesn't add to the practice	14	11.4
Other reasons that might hinder use		
Lack of time	12	9.8
Practitioners get their information in other ways	47	38.2

Note: [a] Frequencies are reported for each theme according to number of data units (i.e. quotations) coded per theme

Practitioners mentioned that other more operational documents exist to guide their specific projects, and that in fact they preferred to use other sources of information to directly address their specific issues. These other sources of information included the reliance on their own personal expertise and experience, collaboration with partners and institutions, and peer-reviewed research. A final reason the restoration professionals in this study did not use the document was simply a lack of time. This reason is not related to the document itself, but more to the demands of the practice, which often leaves practitioners struggling to meet competing deadlines for multiple projects. Many interviewees, especially in the ENGO and private sectors, mentioned that it was hard to stay updated on the latest information, even if that information could ultimately improve their practice. Addressing this issue is beyond the scope of this project, but we felt that it was important to mention in order to generate reflections on potential solutions.

Question 12

One of the last interview questions allowed participants to reflect on the United Nations (UN) Decade on Ecosystem Restoration, which is set to run between 2021-2030. In the original document released by the UN to support this declaration (UNEP, 2020), a report was published which analysed the main barriers to ecological restoration around the world. This report identified six main barriers: 1) public awareness and societal mindsets, 2) political will, 3) legislative and policy environments, 4) technical capacity, 5) research and development, and 6) financing. These barriers were presented to the participants and they were asked to identify the biggest one in the Canadian context. Interviewees identified political will as being the top barrier, with the second in line being financing (Fig. 9).

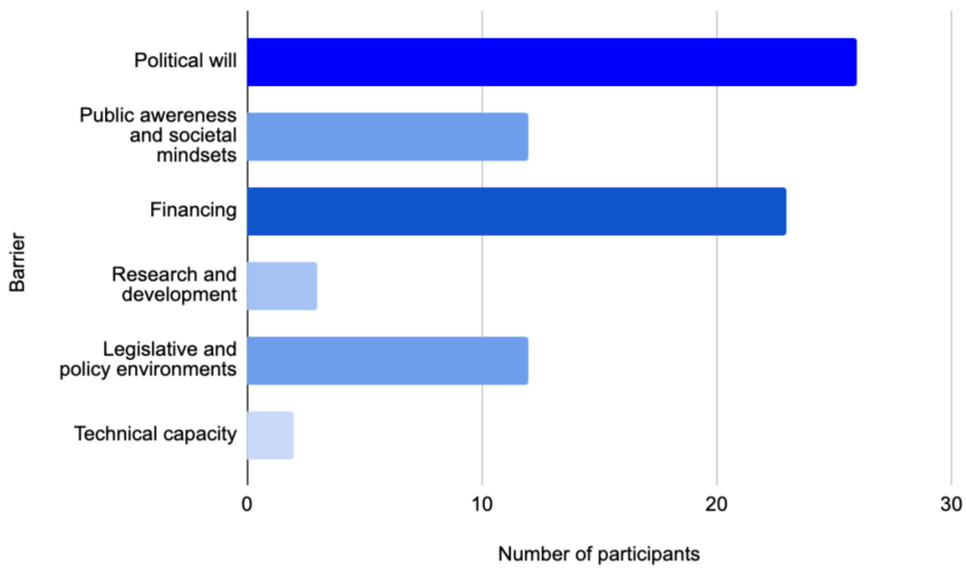

Fig. 9: *Identification of the biggest barrier to ecosystem restoration in Canada by restoration professionals.*

Participants had the opportunity to reflect on these barriers and propose solutions to address them. Many discussed the opportunity of raising public awareness and generating momentum around restoration action through citizen engagement. In this instance, public awareness was not seen as a barrier anymore, but rather as a tool that could be used to shape politics and policies and tap into the potential of ecological restoration for connecting people to their landscapes. Interviewees emphasized the importance of promoting success stories that highlight the benefits of ecological restoration in a way that everyone can understand and connect to.

Participants also touched on the value of establishing and maintaining partnerships with people doing the on-the-ground restoration work, whether those are NGOs, landowners, small community groups, students, or simply volunteers. Maintaining an open dialogue with these stakeholders is essential, as it can ultimately determine which projects get supported and who ultimately contributes to the work. In this sense, many participants addressed the importance of advancing reconciliation, and finding ways to account for and value people’s time, history, and knowledge of the landscape.

Finally, interviewees discussed the need for education and educating youth on principles of ecological restoration from a very young age. Project participants reflected on the role of education to inspire youth, bring hope, and ultimately contribute to future generations becoming more aware of positive impacts of ecological restoration.

Research strengths and gaps

With a participation rate of 87% and over 80 hours of recorded material, one of the greatest strengths of the interview section of this Knowledge Synthesis project was the willingness of ecological restoration practitioners and policy makers to share their time and knowledge with the research team. Within Canada there is a great diversity of people engaged in ecological restoration, from community-based restoration to national and international restoration projects and programs. Using directed and snowball sampling recruitment methods, the research team was able to interview a good cross-section of professionals engaged on the ground in restoration practice as well as policy development at a variety of institutional levels. The interview questions were also well-designed, and allowed participants to expand on a wide variety of restoration-related topics while also addressing the main goals of the study.

However, we also acknowledge some limitations of this project. First, the total sample size of participants (n=69), although quite large for a qualitative study, may not have been sufficient to capture all points of view. Second, it is possible that the higher number of interviewees from British Columbia may have introduced bias in some of the overall responses, with a higher representation of conditions present in that province. Third, due to time constraints not all participants were able to answer each question, which resulted in some questions being less representative of the total sample population. A follow-up interview to complete missing questions would add value to this study, as well as additional recruitment of participants from provinces and territories that were underrepresented.

4.3 Case Studies

4.3.1 Atlantic Salmon Restoration

Project components

Regional stakeholders formed a Recovery Team in 2000 to guide restoration of Atlantic salmon across the inner Bay of Fundy (DFO, 2010). The team is co-led by the Department of Fisheries and Oceans and Parks Canada, and includes Fundy National Park (FNP) representatives, federal agencies, First Nations representatives, provincial governments, conservation NGOs, industry, academia, and special interest groups (DFO, 2010). The Recovery Team has produced two recovery strategies and one action plan (DFO, 2010; DFO, 2019).

FNP started recovery interventions in 2002 when juvenile salmon began to be collected from park rivers to be reared and spawned in captivity as part of the Live Gene Bank (Clarke et al., 2016). This program supplies rivers with the offspring of strategically crossed adult salmon to conserve their genetic diversity. Upon finding that progeny success was lower the longer they experienced captivity (Clarke et al., 2016), FNP led the creation of a complementary recovery program called Fundy Salmon Recovery that allows salmon to hatch in the wild (Fundy Salmon Recovery, 2021). Instead of growing all collected salmon at the Live Gene Bank hatchery, the program grows a portion of them in customized aquaculture net pens (Fig. 10). Adults are reintroduced to park rivers when they are ready to spawn, producing juveniles without captivity exposure. The innovative program is built upon collaboration with the aquaculture industry and long-standing members of the Recovery Team. Across both programs, all life stages of Atlantic salmon are monitored, covering most of the year except winter.

Fig. 10: *Fundy Salmon Recovery grows juvenile Atlantic salmon in a customized aquaculture setting (left) developed in collaboration with Cooke Aquaculture and the Atlantic Canada Fish Farmers Association. Salmon are transferred from the marine farm (center) to Fundy National Park (right) when they reach maturity. Operations are supported by many collaborators (e.g., First Nations, federal agencies, academics, volunteers). Photos by Nigel Fearon Photography for Parks Canada. Adapted with permission.*

FNP plays a major role in engaging the public with Atlantic salmon restoration activities via three visitor experience programs. “Swim with Salmon” teaches participants to identify and count adult Atlantic salmon in snorkel surveys, offering a chance to see them up close while contributing monitoring data. “Be a Biologist” features an interpretive hike for visitors to learn about Atlantic salmon, its history within the park, the reasons for its decline, and monitoring operations. Based on visitor feedback, it was later expanded to include a volunteer training option that has visitors working alongside biologists during the smolt monitoring season (PCA, 2020). “Learn to Fly Fish” commemorates the traditional salmon fishing practice of the local community, which has a large portion of fishers, and aims to offer a way for the cross-generational transfer of the skill. Participants attend a workshop to learn the fishing method and get an opportunity to fly fish brook trout in the park lakes instead.

Policies and perceptions of effectiveness

We found that a mix of policies has shaped the restoration process over time. The Species at Risk Act (SARA) (2002) provides the overarching framework for the recovery of Atlantic salmon in the inner Bay of Fundy region by establishing the conditions for recovery planning. Specific approaches to restoration are chosen by stakeholders through this planning process, resulting in the Recovery Strategy and Action Plan. One of the practitioners interviewed mentioned SARA also influenced the trajectory of restoration within FNP by affording them access to more funding, profile, and leverage. Implementation of restoration actions at the National Park additionally responds to the agency’s mandate to protect and present nationally significant natural and cultural heritage ensuring its integrity for future generations (PCA, 2018c). Furthermore, interventions for ecological restoration follow the guidelines used by the Conservation and Restoration Program of Parks Canada (PCA, 2018b): projects are expected to follow the principles of effectiveness, engagement, and efficiency (Keenleyside et al., 2012), while keeping consistency by applying the Conservation Standards (Conservation Measures Partnership, 2020).

Out of the restoration process, practitioners highlighted the role of collaboration and adaptive management in the trajectory of the project. All three practitioners agreed that collaboration was a key factor for the success of the recovery project so far. Collaboration has happened throughout every phase of the project and has brought together the necessary resources to pursue recovery: people to carry out operations, different areas of expertise, funding, equipment, and facilities. One of the practitioners concluded involving stakeholders early on is a best practice. On the other hand, adaptive management has guided the gradual transformation of recovery interventions and fostered innovation. Two practitioners agreed it was the second most important factor to the success of the project. Practitioners identified challenges in using adaptive management (e.g., allocating time for analysis of ongoing outcomes within a strict funding cycle) and the potential for trade-offs when adapting a project with multiple objectives, but concluded it was an effective approach.

Challenges and opportunities for improvement

All practitioners agreed that continuing to address public engagement was a project priority for FNP. In the short term, FNP plans to adapt current visitor programs to expand their reach and establish working groups with the local community of commercial and recreational fishers. However, advancing the social dimension of the restoration project faces challenges such as the lack of data on past community and public engagement in the park, and the scarcity of staff dedicated to research, especially to social research. Overall, a social science foundation to the conservation program is a gap perceived by one of the practitioners who suggested it could offer a basic understanding of how informed people are about conservation, their sources of information, and how that varies across demographic groups. In the long term, re-establishing more traditional forms of interaction with Atlantic salmon is a prospect subject to the progress of recovery. One of the practitioners suggested some form of angling experience could foster strong community connections and conservation optimism given the importance of angling to the local culture but stressed it would need to be compliant with permitted activities under the Species at Risk Act and not hurt the chances of recovering salmon at FNP.

4.3.2 Peatland Restoration

History of peatland restoration in Canada

In the early 1990s, several events led to the establishment of what has become a long-term Canadian research program on peatland restoration run by academics, the peat industry, and the Canadian government. First, all the actors revolving around the peat environment including companies primarily engaged in peat extraction held a workshop in 1992 to plan for the sustainable management of peat resources, deciding on restoration as the path forwards. At the same time, the Peatland Ecology Research Group (PERG) out of Université Laval was established, bringing together scientists from various disciplines, the Canadian peat industry, and government agencies. After several successful research programmes both in the field and in laboratories, long-term funding was awarded in 1996 which allowed the research to continue. A major Cooperative Research and Development (CRD) grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) was awarded to Dr. Line Rochefort and PERG researchers in partnership with various Canadian peat-producing companies. Funding of PERG research continued in various forms in the 2000s and 2010s, including three five-year terms granted to Line Rochefort as the Industrial Research Chair in Peatland Management, and additional NSERC and industry partner funding. NSERC funding continues to support the research in the 2020s.

Collaborations between the PERG and industry partners were facilitated by annual conferences and technology transfer workshops, as well as a newsletter and website which provide summaries of research publications. After early successes in experimental restoration techniques, a peatland restoration guide for peat managers was published in 1997 (Quinty & Rochefort, 1997). This guide has been updated two times since its first publication, providing more detailed and up-to-date instructions on restoration techniques as research progresses (Quinty & Rochefort, 2003; Quinty et al., 2019, 2020a, b, c). The guide describes what is called "Moss Layer Transfer Technique" (MLTT), which has proven successful in the reintroduction and establishment of bryophytes and vascular plants on ombrotrophic peatlands. The fine-tuning of peatland restoration methods helped improve the ecological value of post-extraction peatlands being restored by peat industry partners in various Canadian provinces: Quebec, New Brunswick, Manitoba, Saskatchewan, and Alberta.

Peatland restoration research

In the 1990s, post-extraction peatlands located in Quebec (Sainte-Marguerite-Marie peatland) and New Brunswick (Maisonnette and Lamèque peatlands) became the first experimental stations for preliminary tests on peatland restoration. Research included the peat chemistry and microtopography of the post-extraction substrate, small-scale *Sphagnum* reintroduction trials, various ways to rewet or conserve moisture at the sites, and the plant and animal species present. Laboratory and greenhouse tests were simultaneously being carried out to better understand the biology of *Sphagnum* mosses: the survival, regeneration, and colonization capacity of diaspores and fragments. The results of this research were used to plan the restoration of 150 ha at the Sainte-Marguerite bog in 1994, using ecological engineering techniques specific to the acid and oligotrophic conditions of the residual peat in this area.

In 2000, an area of 8.4 ha of the Bois-des-Bel peatland, in eastern Quebec, was restored using the restoration method for ombrotrophic peatlands developed by the PERG a few years earlier. Part (3.1 ha) of the bog was selected to act as an unrestored control area. In order to assess the success of restoration operations, a database was created: 755 vegetation sampling points, combined with 57 listening points for birdsong, all georeferenced in a geographic information system. The Bois-des-Bel peatland was a true open-air experimental site, constituting an essential pillar for the constant improvement of peatland restoration methods (Fig. 11).

Fig. 11: *Left, the unrestored sector (28 years) of the Bois-des-Bel peatland (Québec) in 2006 . Right: The Bois-des-Bel peatland (Québec) six years after restoration, in 2006 (photos: PERG).*

As academia-industry partnership continued, it was possible to undertake various research projects with increasingly diverse objectives, such as:

- assessing restoration success of a diverse array of desired attributes by monitoring the long-term evolution of the restored ombrotrophic peatland of Bois-des-Bel, and the return of plant communities in restored peatlands through regular inventories of more than 100 restoration sites across Canada;

- assessing the return of ecosystem functions in restored peatlands, such as ecohydrological regime and carbon sequestration through greenhouse gas exchange measurements;
- developing techniques for restoring fens (brown moss- and sedge-dominated), which have characteristics different from bogs (*Sphagnum* moss-dominated). To that end, three new large-scale experimental sites (20 to 60 ha in size) were created in Quebec, Manitoba, and Alberta;
- developing new restoration approaches for specific environments, such as saline coastal bogs, peatland margins (laggs), and peatland pools;
- how to reclaim peatlands that cannot be restored, including the production of berries (e.g., cloudberry) or coniferous tree planting;
- the cultivation of *Sphagnum* mosses (*Sphagnum* farming) as a renewable resource, which can be used directly for the development of growth substrates or as donor material for the restoration of peatlands.

Successes from collaboration

Since its development in the late 1990s, the Moss Layer Transfer Technique has enabled the Canadian peat industry to restore an ever-increasing number of peatlands (mostly *Sphagnum* peatlands) in the country. Specifically, more than 110 peat-extracted sites (2019 statistics) have been restored nationally in Quebec, New Brunswick, Manitoba, Saskatchewan and Alberta, covering more than 1,800 hectares. The term “restoration site” designates a sector of an extracted peatland that was restored within a given year; consequently under slightly different management actions and sometimes under widely different annual weather conditions. Restoration sites might be located 2–5 km apart within the same peatland complex or in different peatland.

Monitoring of these peatland sites indicated that this large-scale mechanized technique of restoration has successfully reintroduced and established bryophytes (*Sphagnum* and *Polytrichum*) and vascular plants for ombrotrophic peatlands within five years after restoration (González et al., 2013, 2014). It facilitates the return of 82% of the biodiversity of vascular plants (Hugron et al., 2020). The technique is effective for reestablishing hydrological attributes (Taylor et al., 2016). It also leads to a return of peat accumulation and to restore the carbon sink function (Nugent et al., 2018; Strack & Zuback, 2013). It was also demonstrated that management plans that include prompt active restoration is key to utilizing peatland restoration as a climate change mitigation strategy (Nugent et al., 2019). The work of González and Rochefort (2019) led to the creation of a statistical tool to define the success of the application of MLTT on degraded peatlands. The main advantage of this tool is that it uses simple indicators based on the vegetation layer; it can also be used throughout Canada.

Research strengths and limitations

In the USA, the National Science Foundation created a program at the beginning of the 1980s to support long-term monitoring and research (LTER) to the key ecosystems of the United States. In Canada, we do not have such a program but also in the mid 1980s NSERC (Natural Science and Engineering Research Council of Canada) developed an academia-industry partnership funding programs (CRD, Industrial Chairs) that matched 1:1 industrial funds in university research. It is through this long-term, sustained and joint funding of university research by the Canadian government and the peat industry that we now know how to restore Sphagnum peatlands in all kinds of conditions across the country. This is a unique opportunity to demonstrate how a partnership between academia and industry can create synergy to help advance knowledge on both practical and fundamental sides. The team of researchers in the Peatlands Ecology Research Group (PERG) is recognized as one of the world leaders in ecological restoration of peatlands. Due to the long-term funding of the group, PERG has unique databases, covering restoration sites across Canada and long periods of monitoring (up to 28 years) about the efficiency of restoration actions, which allows evaluating the success of the different peatland management options.

Indeed, one of the strengths of this long-term research on peatland restoration is the development of simple and easily measurable criteria for evaluating the success of restoration, based on the return of plant communities and of a water regime typical of peatlands, as well as the return of long-term carbon sequestration. Still in partnership with the Canadian peat industry, researchers are continuing studies to answer various questions that have emerged during the work of recent years. For example, it appears that the MLTT does not give results as convincing for the restoration of minerotrophic peatlands as those obtained for ombrotrophic peatlands with regard to the reestablishment of a flora typical of the restored ecosystem. Continued research into peatland restoration guarantees greater success in restoration efforts from coast to coast in Canada. It helps inform governments to develop better laws, regulations, policies, and programs for responsible peatland management across the country. It also provides verifiable evidence that the Canadian peat industry is complying with international conventions as proof of its investment in good corporate citizenship.

4.3.3 Garry Oak Ecosystem Restoration

Landscape and social context

Garry oak and associated ecosystems are found in the dry rain shadow of the Vancouver Island mountain range in coastal British Columbia. Many Garry oak ecosystems were established and maintained by traditional land management of Coast Salish Peoples, in particular practices such as prescribed fire and the harvest of food plants like Camas (*Camassia* spp.*;* Fuchs, 2001; Pellatt & Gedalof, 2014). Intentional, controlled burns in Garry oak meadows contributed to increased productivity of traditional food plants and helped maintain open meadows in the landscape (Turner, 1999), while harvesting of root plants turned soils over and encouraged higher productivity due to selective harvesting practices (Turner, Ignace, &

Fig. 12: *Map of 102 Garry oak ecosystem restoration projects in Canada, located during the case study.*

Ignace, 2000). Most of these ecosystems have lost their traditional land management by First Nations as a result of European colonization and the forcible displacement of First Peoples (Fuchs, 2001; Pellatt & Gedalof, 2014). This loss of traditional management, coupled with the suite of exotic species associated with colonization, has led to new and different disturbance regimes impacting the landscape.

The most recent estimate, from 2006, suggests that only 5% of pre-European-contact Garry oak ecosystems remain in a relatively naturalized state (Lea, 2006). Garry oak ecosystems are considered one of Canada's most at-risk ecosystems, and face three major threats: habitat loss, fragmentation, and degradation. Degradation is caused by a combination of invasive species, hyper-abundant native and introduced herbivores, recreational use, and exclusion of fire (GOERT, 2011). As a result, for at least the last three decades, concerned and passionate people have been restoring these ecosystems. There are at least 100 current or completed projects that sought to restore Garry oak ecosystems in Canada (Fig. 12).

Community organizations

Garry oak ecosystem restoration has often been spearheaded as part of species at risk recovery, and/or by community groups and volunteers. Current restoration in Canadian Garry oak ecosystems is supported by significant work initiated and pursued by the Garry Oak Ecosystems Recovery Team (GOERT), a volunteer-based organization centered in Victoria, BC. Established in 1999, their goal was "to provide a cooperative and coordinated long-term approach to conserving what is left of Garry oak and associated ecosystems and species at risk." (Smith et al., 2006, p.1). This group continues to manage a website with extensive publications on restoration best practices, stories of ongoing restoration efforts, and manage annual conferences. Additionally, the Cascadia Prairie Oak Partnership was founded in the United States (US) in 2010 and connects practitioners across the full range of Garry oak ecosystems in Canada and the US through triennial conferences, a digital technical library, and a listserv that is actively used by Canadian and American restoration practitioners. These organizations create a community of practitioners and facilitate knowledge-sharing at multiple scales.

Restoration projects

A total of 102 restoration projects in Garry oak ecosystems within Canada were identified (Fig. 12). FOr the project we found, current restoration projects are being completed largely within protected areas such as municipal and regional parks, provincial parks, and federal parks and park reserves. Across 50 projects, there were at least 54 groups, organizations, or individuals involved in the restoration projects, many involved in multiple projects. Some projects included more than 10 partners. In addition, a large community of researchers from different institutions and public offices collaborate to research both restoration techniques and important ecological and biological foundations within the ecosystem. In 2009, GOERT recorded 40 Canadian researchers of Garry oak ecosystem restoration specifically, and an additional 54 focusing on ecosystem classification and function, rare species biology, disturbance regimes, invasive species, and fragmentation from a range of organizations (GOERT, 2009, unpublished document). Additionally, 54 papers on ecology and 11 on restoration in these ecosystems were found in the literature search, published between 1995 and 2019.

Volunteers contribute immensely to the labour in these restoration projects, with more than a thousand individuals contributing to Garry oak ecosystem restoration projects in a given year. The total reported hours from 14 projects included about 51 000 hours of work (~31 person-years of labour or $1.02 million of labour at a $20/hour wage), roughly 22 % of which were reported from Uplands Park over a 6-year period, and 14 % from a single volunteer over a 10-year period. Additionally, GOERT reported a range between ~2.5 - 6 person years, per year, of volunteer work in their projects. The available values are incomplete for each project, and many projects aren't represented in them. As such, it is reasonable to assume these numbers vastly underestimate the hours contributed by volunteers.

Common restoration treatments currently being used include invasive species management, fencing, conifer removal/girdling, and addition of native plants. Other treatments include prescribed fire, mowing, mulching, and species at risk re-introductions or supplementation. These treatments correspond to the main methods of restoration identified in GOERT's 2011 "*Principles and Practices*…" best-practices publication. Invasive species impact the health and persistence of native plants through competition for resources, altering the habitat (e.g. hydrology and thatch changes), and through predation/herbivory (GOERT, 2011); they are thought to be the second greatest threat to these ecosystems. Management of invasive species was the most common technique among projects, with at least 33 projects including invasive species management in their restoration work. Several restoration projects have prioritized reconnecting First Nations stewardship and traditional management practices to their historical landscapes. In some of the most developed examples, this effort has taken the shape of collaborative reintroduction of fire management. Returning fire to the landscape is difficult in many Garry oak sites because of their location in cities, but as a restoration tool provides an opportunity to re-integrate the landscape into the cultural context in which they developed (Pellatt & Gedalof, 2014). For those projects that added native plants (15 projects) the numbers and selection of species varied widely. Camas and native grasses were often added, with anywhere from a few to over a hundred species of native plants being added. Most commonly seeds were used to add native plant propagules to a site but plugs, pots and seedlings were also used.

Planning and monitoring information was less commonly available than restoration techniques. For many sites where it was available, it was in part because of the presence of species-at-risk and associated reporting requirements. We found that 26 projects included some kind of restoration goal associated with their project, but formal restoration plans were uncommon and/or difficult to locate. Some practitioners cited limited funding as a barrier to comprehensive planning. Monitoring included a mixture of quantitative measures (13 projects), particularly for rare plant inventories, or in permanent vegetation plots, and qualitative measures (9 projects), often to assess invasive species persistence, or through photo monitoring. The frequency of monitoring efforts varied greatly between projects – some with a single quantitative monitoring event, others with permanent vegetation plots measured annually for 12 years. Some projects employed a mix of qualitative and quantitative measures.

Research strengths and limitations

The case study achieved a good spread of restoration approaches used in different organizations. We identified over 100 restoration projects occurring within Canadian Garry oak ecosystems, and examined 41 projects managed by at least eight different organizations or groups. These organizations included federal, provincial, and municipal government organizations, not-for-profits, and volunteer groups.

Limitations to this work include: the evaluation of projects based on those with the most available information, lack of information on indigenous-led restoration efforts, and lack of information on restoration success. Since many projects lacked formalized information on methods and outcomes, the analysis was limited to projects for which information was most readily available. Projects being undertaken in National Parks and by First Nations were not represented in our dataset. This gap likely means that rigorous monitoring programs with clearly described restoration outcomes were missing, as well as a representation of restoration methods informed by traditional knowledge and linked to community-led cultural restoration projects in these ecosystems. Additionally, information on restoration success was often informal or missing for the projects we examined. So, while it is clear that much effort is being contributed to restoration in this ecosystem, from this project we are unable to assess the degree of success being achieved. These limitations highlight opportunities for future research.

5.0 IMPLICATIONS

5.1 Literature Review

This portion of the study revealed that ecological restoration knowledge generation in Canada is highly collaborative, diversified across fields and institutions, and is increasing in activity. This, coupled with the interdisciplinary nature of ecological restoration and multi-dimensional contexts associated with it (social, ecological, economic), gives the implication that future research must continue to build relationships among institutions across the world, between Canadian institutions, and between professional researchers and community level/private sector restoration experts. There are areas where there are clear silos. For example, the chemical remediation literature has little crossover with the literature more focused on abiotic physical and biotic restoration methods. However, all researchers are working to reverse degradation and future research that integrates currently siloed fields within restoration can work towards that shared purpose.

Thematically, Canadian ecological restoration literature is quickly turning its attention to climate change, implying that there is a growing recognition of the potential role of restoration in climate change mitigation and control. There is also growing focus on the impact of climate change on ecological restoration outcomes. Policy should take notice of this obvious recognition in published literature, and support ongoing efforts to implement ecological restoration as a tool in the climate change fight. Restoration research in Canada also needs to grapple with the changing climatic realities which may affect the performance of restoration techniques.

The absence of grey literature, private organization-led restoration, and community level restoration in published literature demonstrates a need for greater collaboration between academics and non-academic restoration experts. More effort is needed by all parties to bridge the communication gap and use the strengths of each party to ensure that valuable restoration knowledge is made accessible and communicable to restoration practitioners in all sectors. Knowledge mobilization needs to be a part of restoration research. All papers should explore implications for professionals. *Restoration Ecology* requires this in its submissions, but other journals seldom report implications.

Major methodological gaps are identified which can be used to guide future research and increase the potential for systematic review of restoration techniques. Target species groups are almost always of a single trophic level, which prevents research from establishing multi-trophic and complete ecosystem responses to restoration methods. There is a continued reliance on short term monitoring studies which are likely to be insufficient at capturing true ecosystem responses to disturbance, restoration, and stewardship. Restoration literature lacks standardization of certain responses, outcomes, and methods, making comparisons between studies challenging. Typical systematic reviews require standardized study methodologies to compare results across time and space.

There is a strong emphasis in the published literature toward restoration of the degradation caused by a few natural resource extraction industries across Canada, likely a product of regulatory requirements, direct industry support for research, or other mobilized research funding. Restoration in other industries and on smaller scales requires additional support (e.g. funding, policy, regulatory, and political) to capitalize on their importance in driving social, ecological, and economic sustainability. It is evident that all forms of restoration could use additional emphasis and resourcing, and there are several that are distinctly less represented (e.g., arctic and alpine ecosystems; urban ecosystems).

Centralized databases for ecological restoration knowledge in Canada would help to promote accessibility and knowledge sharing. Presently, literature is scattered widely, difficult to obtain, and poorly searchable. Additionally, it may be helpful to work towards bridging the silos in restoration. A great deal of published ecological restoration research is rooted in forestry. The reforestation literature within Canada is quite deep, and while its goals may be different from ecological restoration, there is much knowledge to share. Published research is largely considered with one narrow aspect of a restoration project - for instance, the performance of a particular species under a given treatment. While this narrow focus is a hallmark of science, it misses the broader ecosystem-wide picture.

The geographical concentration of ecological restoration studies focused on three main areas: Alberta oil sands, Sudbury lakes and the Bois-des-Bel peatland research station. The concentration of restoration research in Sudbury, Ontario is a sign of a legacy of ecological restoration in that area. It is important to acknowledge current events -- the bankruptcy of Laurentian University in that city is expected to greatly damage the advancement of science in restoration knowledge. This literature review serves as evidence of Laurentian’s outsized contribution to the field of ecological restoration.

Going forward there is potential for ecological restoration to benefit from systematic reviews which gather and synthesize evidence for a given treatment. However, there will be challenges in the heterogeneity of data that is collected. Efforts to move restoration science towards standardized data collection should be promoted as a means of enhancing the ability to produce sound evidence for restoration techniques.

5.2 Practitioner Interviews

Canada has played an important role in the development of ecological restoration practice, by publishing some of the earliest national guidelines on restoration (Parks Canada & Canadian Parks Council, 2008) and contributing to international policy and guidance in this field (Keenleyside et al., 2012). However, based on this project’s interview responses, it seems that many restoration practitioners in this country see ecological restoration as an emerging field, not yet fully developed. While it may be tempting to view these responses in a negative light, we believe that it is important to acknowledge the potential this may offer. A discipline that is viewed as emerging is one that is not yet constrained by narrowing definitions and the increase in often confusing terminology of related fields. It may still hold the potential to be flexible and adapt to challenges that are associated with rapidly changing climatic conditions (Higgs, Harris, Heger, et al., 2018). While it is unclear whether ecological restoration in Canada is on a set trajectory to become more narrow and constricted as it matures as a discipline, this project highlights that for a diverse array of practitioners, the opportunity remains for the field to continue to grow and adjust itself to the demands of increasingly complex ecological challenges.

If Canadians are to take advantage of the emerging nature of this field, then proper guidance will be needed to support restoration professionals in their practice and decision-making. While many different organizations at the national and international level have developed different forms of guidance over the years, the Society for Ecological Restoration (SER) has taken a leadership role in building a community for restoration practitioners rooted in the science and practical application of the discipline since its inception in 1988 (Davis & Slobodkin, 2004). Over the last two decades, SER has published a primer on ecological restoration (SER, 2004), and more recently a set of principles and standards (Gann et al., 2019). While critique and debate arose around both documents (Gann et al. 2018; Higgs, Harris, Murphy et al., 2018a,b; Shackelford et al., 2013) these publications were designed to meet the increasing needs of practitioners for unifying guidance that would allow for restoration work to be conducted and evaluated in a systematic manner. The 2019 document went further by also clarifying the breadth of the discipline and associated practices, and providing tools to facilitate the planning and implementation of restoration projects.

To our knowledge, our study represents the first evaluation of these principles and standards by a diverse group of restoration practitioners and policy makers. Our analysis shows that while some practitioners are aware of the document and are using it as a reference to evaluate restoration proposals, the majority are not engaging with the publication. To this end, three issues emerged which need to be addressed if this document is to represent a main source of information for restoration professionals: 1) accessibility, 2) structure and format, and 3) operability. As was highlighted by interviewees, accessibility can represent a major barrier to the uptake of the publication. In this sense, a document that is meant to provide guidance on restoration action should be inclusive of all people that are engaging with restoration, regardless of educational background and career aspirations. This document should also be simple and easy to understand, so that anyone is able to follow and apply what is presented. Complicated concepts and numerous principles can hinder comprehension and adoption of a guiding document. Finally, due to the practical nature of the field, the publication needs to directly apply to on-the-ground situations. Restoration practitioners deal with various issues, which complicates the development of a one-size-fits-all approach that would be suitable to all situations. There is also a disjunction between restoration theory and practice, with lag times appearing between the time theory is developed and applied which may ultimately muddle further applications. The recommendation here would be to perhaps not attempt to develop guidance to suit each and every need, but to allow enough flexibility in the proposed concepts such that practitioners can adapt them to specific projects.

Finally, if Canada is to continue its leading contribution to the global restoration community, key barriers need to be addressed. This project underlined challenges with regards to mobilizing the political will to generate and financially support restoration action in the long-run. Participants believed that in order to be able to elevate the importance of ecological restoration to politicians and decision-makers it is necessary to build up public awareness of the practice. In this sense, showcasing small scale community-based projects could be an effective way to allow people to see the benefits of restoration action, by displaying places they can easily identify. Sharing stories about failures is also important. It may be difficult to do because the public does not generally want to hear about negative outcomes, but restoration is a practice that is still evolving, and these failures could actually be seen as valuable learning opportunities.

At its core, ecological restoration is a practice that brings hope and allows people to connect with their natural environments (Egan et al., 2011). It is a practice that fosters long-term stewardship between people and ecosystems (Higgs, 1997). By opening up the dialogue and bringing in together different perspectives, it may be possible to generate the momentum required to successfully scale-up restoration action, for this decade and the many to come.

5.3 Case Studies

5.3.1 Atlantic Salmon Restoration

While best practices for ecological restoration typically cite the need to work collaboratively in early stages, projects too often omit this step. As the interviewees noted, that step was – in their opinion – key to success at Fundy National Park. This is consistent with the literature where ecological restoration successes depended most on this phase (Allison & Murphy, 2017). The nature of the collaboration varies with project scope and stakeholders, but care must be taken to identify both actors and should-be actors (Gann et al., 2019; Higgs, Harris, Heger, et al., 2018; Higgs, Harris, Murphy, et al., 2018a).

Once implementation of a restoration plan begins, novel and unforeseeable issues usually arise. Collaboration efforts must continue as an adaptive management framework and action plan will be needed to accomplish the original or modified restoration goals (Gann et al., 2019; Murphy, 2018). These need to be agreed upon, justified, and documented. In the case of FNP, this seems to be what occurred; a longer-term study would be needed to determine exactly how much adaptive management was used and how that was constructed (*viz* Allison & Murphy, 2017).

While there are debates over whether ecological restoration is policy driven – because there are few policies that are specific to the discipline and little formal social science analysis to date – research reveals that policies governing resource development and conservation affect ecological restoration planning, management, and outcomes (Baker & Eckerberg, 2013; Jørgensen et al., 2013). This is critical if there is a high risk to failure (Allison & Murphy, 2017), as when addressing endangered species like salmon in FNP. Meeting the expectations of local stakeholders (e.g., recreational fishers) may be challenged by the legal and ethical requirements to manage and restore endangered species. In the case of FNP, this arose in terms of potentially engaging the community via angling, which would be subject to prohibitions by the Species at Risk Act (2002). Because recovering Atlantic salmon will still require long term efforts, discussing future forms of community engagement is important, especially as it concerns an activity like angling that may support conservation (Cooke et al., 2019). A pathway for future policy-making (e.g., updating the recovery strategy) may be to define when more activities might be allowed as restoration benchmarks are achieved (see Allison & Murphy, 2017).

5.3.2 Peatland Restoration

Peat extraction is an important commercial and industrial activity located in rural and often remote areas of Canada and even if widely dispersed throughout the country, the companies have the will to manage their resources responsibly. As peatlands provide many useful ecosystem services to human populations, in particular carbon sequestration, peatland ecosystem restoration is one of the most cost-effective solutions to mitigate the effects of global warming (Griscom et al., 2017; Nugent et al., 2019). The Canadian peat industry has the Certification for Responsibly Managed Peatlands - an international first -, which guarantees the application of good management practices in all aspects of sustainable development. The program is administered by an independent certification agency, the Scientific Certification Systems (SCS), which is one of the most recognized agencies in North America. The Canadian peat industry also introduced a national peatland restoration policy to reduce the area of sites closed to production which have not yet been restored.

The Moss Layer Transfer Technique (MLTT) and other restoration techniques developed by the Peatland Ecology Research Group are constantly being optimized to allow their use to be broadened to restore various types of disturbance to peatlands, such as drilling platforms for the oil sands (Gauthier et al., 2018; Lemmer et al., 2020), roads and other linear disturbances (Pouliot et al., 2021). Furthermore, several large-scale peatland restoration projects have been carried out all over the world with the MLTT.

The group's expertise in peatland restoration is often called upon for various environmental questions, for example: Hydro-Quebec, governments (Environment Canada, Ministère des Transports du Québec, Ministère de l'Environnement et de la Lutte contre les changements climatiques, Ministère de l'Énergie et des Ressources naturelles, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec), collaborators from around the world (notably within the International Peatland Society and the International Mire Conservation Group), the petroleum industry (Suncor, Shell, Total, Esso Imperial, Japan Oil Sands, ConocoPhillips Canada), and the Association of Quebec Cranberry Producers. The group's success in restoring peatlands has led several provincial governments to modify their wetland policies. Some now require restoration measures for disturbances in peatland ecosystems (New Brunswick, Quebec, Manitoba and Alberta), or to start reviewing their policy (other Maritime provinces and Saskatchewan). The Moss Layer Transfer Technique is even at the origin of the Crown Peat Policy adopted by the Government of New Brunswick (available here).

5.3.3 Garry Oak Ecosystem Restoration

Our findings highlight several key opportunities: developing tools, processes, or policies that support the planning, monitoring, and reporting of restoration outcomes, maintaining existing knowledge-sharing structures, and increasing cultural restoration as a component of ecosystem restoration projects. Few of the projects we reviewed had formal planning or ongoing monitoring efforts. Formal restoration plans or follow-up reporting describing restoration activities and lessons learned were difficult to access. Additionally, many researchers in Garry oak ecosystem restoration were associated with government or other non-academic institutions, which increases the likelihood that research results would be maintained in unpublished internal reports that are challenging to access. Research into the best methods to support planning and reporting would be beneficial, particularly in projects with limited funding for such activities, or organized by volunteers, who may prefer active restoration intervention to reporting.

The Garry Oak Ecosystems Recovery Team plays a critical role in collecting and sharing restoration knowledge for Garry oak ecosystems in Canada by providing a centralized resource. Maintaining a central resource and organizing node seems like an effective method to continue supporting

Garry oak ecosystem restoration in Canada. Funding and policies that support long-term information sharing efforts are likely to support restoration in communities with large volunteer bases.

Finally, as culturally-derived ecosystems, it is appropriate to consider cultural restoration as a key part in restoring the ecological function of these ecosystems. For municipalities, building and fostering relationships with local First Nations would ensure opportunities are available to discuss cultural restoration within municipal sites, where much of the restoration is occurring.

6.0 CONCLUSION

At the start of this project, our objectives were to synthesize and critically assess the state of ecological restoration knowledge in Canada and to identify and assess restoration policy in Canada. We did so by reviewing the existing published academic literature, speaking with a diverse group of Canadian restoration practitioners, and examining three distinct cases: species at risk recovery by a leader in restoration: Parks Canada, peatland restoration from over 25 years of partnerships between industry and academia, and community-led restoration in one of the most at-risk ecosystems in Canada. A major theme from the project findings is the collaborative nature of restoration in Canada, both in the co-production of knowledge and in the development and implementation of restoration projects. In the academic literature, there is also a theme of increasingly considering the impacts of climate change on ecosystems, how to incorporate that into restoration planning, and the potential to use restoration as a tool to mitigate climate change.

Areas where existing policies seem to support restoration include species at risk protections and industrial requirements. Two of the case studies examined areas where species at risk fuel a number of restoration actions. The federal Species at Risk Act provides funding streams for species-at-risk on federal lands (the Interdepartmental Recovery Fund) and on non-federal lands (the Habitat Stewardship Program). Funding from both of these streams was used in many Garry oak ecosystem restoration projects. However, for those projects run by or led by volunteers and where rare species expertise is not available to assess the presence of species at risk, these resources remain unavailable. Strong industrial partnerships in the service of finding more effective and efficient approaches to restoration can be supported by robust policies and mobilizing funding. In some cases, such as the peatland case study, it may also be evidence of industrial desires to sustainably manage a resource. Future research could involve targeted assessments of the role of specific policies (such as policies governing oil sands reclamation practices) on restoration innovation and practice, as well as chosen restoration outcomes. Other policies may be practical at the municipal level, where communities integrate ecosystem restoration into community planning which creates structures that support restoration. High-level policies could assess common sources of degradation, and find ways to prevent them or mitigate them prior to restoration, such as making the sale of known invasive plants across the country illegal.

In some areas our project faced challenges accessing knowledge, likely because of the disconnect between the nature of knowledge and how it is transmitted. Grey literature was noticeably difficult to access for research purposes, or lacking, but it is where on-the ground lessons from restoration are often stored. Developing better tools to transmit local knowledge, and to develop methods for researchers to analyze it would help us to understand what is happening on the ground for the multitude of projects occurring without any reporting requirements. The practitioner interviews highlighted that practitioners also don't have time to access new information. There may be room for municipal-level policies that support both reporting and opportunities to share information for their projects, however this change would inherently require more funding at the municipal level to support the policies. Additionally, accessing and assessing traditionally ecological knowledge and indigenous knowledge relating to restoration in Canada requires a different approach from analyzing published literature and grey literature. It also often requires a different approach to formulating research questions. Methods that protect indigenous knowledge ownership, and to follow culturally appropriate modes of sharing information need to be used. These methods are not often intuitive to those conducting research and may vary greatly across the diverse indigenous nations in Canada. Supporting research partnerships to further develop these methods and which focus specifically on indigenous knowledge so that methods can match outcomes would be of value.

7.0 KNOWLEDGE MOBILIZATION ACTIVITIES

Our project focuses on providing support to all those who want to achieve ecological restoration that yields the most possible benefit, including dissemination of our research findings as widely as possible. Although our primary audience for this work are scientists, practitioners, and decision-makers in Canada, we will publish our literature review in an international journal (open access) and thus share it with the broader community. We aim to reach a wide audience through diverse modes of discovery: technical and academic avenues, public reporting available for skimming and deep dives, and social media for spontaneous discovery. Final knowledge mobilization products include: a symposium at the Society for Ecological Restoration international conference (June 2021), academic publications, a comprehensive and public website (ecologicalrestorationincanada.ca) on which to gather project outcomes, and social media outputs. The website will include recorded conference talks, a brief 2-page summary of each project component for "skimmers" and a 10-page report on each component for "deep divers". The website will continue to be updated with publications and communication related to the project. Social media will help engage with both younger and broader demographics and allow users to be knowledge creators by sharing information that they find interesting and novel.

BIBLIOGRAPHY

Allison, S. K., & Murphy, S. D. (Eds.). (2017). *Handbook of Environmental and Ecological Restoration*. Routledge Press.

American Association for Public Opinion Research. (2016). *Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys.* 9th edition. AAPOR. https://www.aapor.org/AAPOR_Main/media/publications/Standard-Definitions20169theditionfinal.pdf

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Baker, S., & Eckerberg, K. (2013). A policy analysis perspective on ecological restoration. *Ecology and Society*, *18*(2), 17. http://dx.doi.org/10.5751/ES-05476-180217

Clarke, C. N., Fraser, D. J., & Purchase, C. F. (2016). Lifelong and carry-over effects of early captive exposure in a recovery program for Atlantic salmon (*Salmo salar*). *Animal Conservation, 19*(4), 350-359. https://doi.org/10.1111/acv.12251

Conservation Measures Partnership. (2020). *Open standards for the practice of conservation* [Version 4.0]. https://conservationstandards.org/download-cs/

Cooke, S. J., Twardek, W. M., Reid, A. J., Lennox, R. J., Danylchuk, S. C., Brownscombe, J. W., Bower, S. D., Arlinghaus R., Hyder, K., & Danylchuk, A. J. (2019). Searching for responsible and sustainable recreational fisheries in the Anthropocene. *Journal of Fish Biology, 94*(6), 845-856. https://doi-org.proxy.lib.uwaterloo.ca/10.1111/jfb.13935

Corbin, J., & Strauss, A. (2008). Integrating categories. In *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed., pp. 263-274). SAGE Publications, Inc. https://dx.doi.org/10.4135/9781452230153

Davis, M. A., & Slobodkin, L. B. (2004). The science and values of restoration ecology. *Restoration Ecology*, *12*(1), 1-3. https://doi.org/10.1111/j.1061-2971.2004.0351.x

Department of Fisheries and Oceans Canada (2010). *Recovery Strategy for the Atlantic salmon* (Salmo salar), *inner Bay of Fundy populations* [Final]. Species at Risk Act Recovery Strategy Series. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/rs_atlantic_salmon_ibof_0510a_e.pdf

Department of Fisheries and Oceans Canada (DFO) (2019). *Action Plan for the Atlantic Salmon* (Salmo salar), *inner Bay of Fundy population in Canada*. Species at Risk Act Action Plan Series. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Ap-SaumoniBoFSalmon-v00-2019Sept-Eng.pdf

Egan, D., Hjerpe, E. E., & Abrams, J. (2011). Why people matter in ecological restoration. In Egan, D. (Ed.), *Human dimensions of ecological restoration* (pp. 1-19). Island Press, Washington, DC.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107-115. doi: 10.1111/j.1365-2648.2007.04569.x.

Fuchs, Marilyn A. (2001). Towards a Recovery Strategy for Garry oak and Associated Ecosystems in Canada: Ecological Assessment and Literature Review. Technical Report GBEI/EC-00-030. Environment Canada, Canadian Wildlife Service, Pacific and Yukon Region.

Fundy Salmon Recovery. (2021). *Our project – Fundy Salmon Recovery project*. https://www.fundysalmonrecovery.com/our-project/

Fusch, P. I., & Ness, L. R. (2015). Are we there yet? Data saturation in qualitative research. *The Qualitative Report*, *20*(9), 1408-1416. https://doi.org/10.46743/2160-3715/2015.2281

Gann, G., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J. G., Eisenberg, C., Guariguata, M. R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, N., & Dixon, K. W. (2019). International principles and standards for the practice of ecological restoration. Second edition. *Restoration Ecology*, *27*(S1), S1-S46. https://doi.org/10.1111/rec.13035

Gann, G. D., McDonald, T., Aronson, J., Dixon, K. W., Walder, B., Hallett, J. G., Decleer, K., Falk, D. A., Gonzales, E. K., Murcia, C., Nelson, C. R, .& Unwin, A. J. (2018). The SER Standards: a globally relevant and inclusive tool for improving restoration practice—a reply to Higgs et al. *Restoration Ecology*, *26*(3), 426-430. https://doi.org/10.1111/rec.12819

Gauthier, M.-E., Rochefort, L., Nadeau, L., Hugron, S., & Xu, B. (2018). Testing the moss layer transfer technique on mineral well pads constructed in peatlands. *Wetlands Ecology and Management* *26*(4), 475-48. https://doi.org/10.1007/s11273-017-9532-4

Garry Oak Ecosystems Recovery Team (GOERT) (2009). *Garry Oak Related Research/Researchers.* Unpublished document.

Garry Oak Ecosystems Recovery Team (GOERT) (2011). *Restoring British Columbia's Garry Oak Ecosystems - Principles and Practices*. http://www.goert.ca/documents/restorationbooklet/GOERT-restoration-booklet-all.pdf

González, E., Rochefort, L., Boudreau, S., Hogue-Hugron, S., & Poulin, M. (2013). Can species indicators predict restoration outcomes early in the monitoring process? A case study with peatlands. *Ecological Indicators*, *32*, 232–238. https://doi.org/10.1016/j.ecolind.2013.03.019

González, E. & Rochefort, L. (2014). Drivers of success in 53 cutover bogs restored by a moss layer transfer technique. *Ecological Engineering*, *68*, 279–290. https://doi.org/10.1016/j.ecoleng.2014.03.051

González, E. & Rochefort, L. (2019). Declaring success in *Sphagnum* peatland restoration: Identifying outcomes from readily measurable vegetation descriptors. *Mires and Peat*, *24*(19), 1-16. DOI: 10.19189/MaP.2017.OMB.305

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R.T., Delgado, C., Elias, P., Gopalakrishna, T., … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645-11650. https://doi.org/10.1073/pnas.1710465114

Hayes, A. F., & Krippendorff, K. (2007). Answering the call for a standard reliability measure for coding data. *Communication Methods and Measures*, *1*(1), 77-89. https://doi.org/10.1080/19312450709336664

Higgs, E. S. (1997). What is good ecological restoration? *Conservation Biology*, *11*(2), 338-348. https://www.jstor.org/stable/2387608

Higgs, E. S., Harris, J. A., Heger, T., Hobbs, R. J., Murphy, S. D., & Suding, K. N. (2018). Keep ecological restoration open and flexible. *Nature Ecology & Evolution*, *2*(4), 580-580. https://doi.org/10.1038/s41559-018-0483-9

Higgs, E., Harris, J., Murphy, S., Bowers, K., Hobbs, R., Jenkins, W., Kidwell, J., Lopoukhine, N., Sollereder, B., Suding, K., Thompson, A., & Whisenant, S. (2018a). On principles and standards in ecological restoration. *Restoration Ecology, 26*(3), 399-403. https://doi.org/10.1111/rec.12691

Higgs, E., Harris, J., Murphy, S., Bowers, K., Hobbs, R., Jenkins, W., Kidwell, J., Lopoukhine, N., Sollereder, B., Suding, K., Thompson, A., & Whisenant, S. (2018b). The evolution of Society for Ecological Restoration's principles and standards—counter-response to Gann et al. *Restoration Ecology*, *26*(3), 431-433. https://doi.org/10.1111/rec.12821

Hugron, S., Guêné-Nanchen, M., Roux, N., LeBlanc, M-C., & Rochefort, L. (2020). Plant reintroduction in restored peatlands: 80% successfully transferred – Does the remaining 20% matter? *Global Ecology and Conservation*, *22*. https://doi.org/10.1016/j.gecco.2020.e01000.

Jones, H. P., Jones, P. C., Barbier, E. B., Blackburn, R. C., Rey Benayas, J. M., Holl, K. D., McCrackin, M., Meli, P., Montoya, D., & Mateos, D. M. (2018). Restoration and repair of Earth's damaged ecosystems. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1873). https://doi.org/10.1098/rspb.2017.2577

Jørgensen, D., Nilsson, C., Hof, A. R., Hasselquist, E. M., Baker, S., Chapin III, F. S., Eckerberg, K., Hjältén, J., Polvi, L., & Meyerson, L. A. (2013). Policy language in restoration ecology. *Restoration Ecology*, *22*(1), 1-4. https://doi.org/10.1111/rec.12069

Keenleyside, K.A., Dudley, N., Cairns, S., Hall, C.M., & Stolton, S. (2012). *Ecological restoration for protected areas: Principles, guidelines and best practices*. International Union for Conservation of Nature (IUCN). https://www.iucn.org/content/ecological-restoration-protected-areas-principles-guidelines-and-best-practices

Lea, T. (2006). Historical Garry Oak ecosystems of Vancouver Island, British Columbia, pre- European contact to the present. *Davidsonia*, *17*(2), 34-50.

Lemmer, M., Rochefort, L., & Strack, M. (2020). Greenhouse gas emissions dynamics in restored fens after in-situ oil sands well pad disturbances of Canadian boreal peatlands. *Frontiers in Earth Sciences* 8: 557943; https://doi.org/10.3389/feart.2020.557943

Murphy, S. D. (2018). Restoration Ecology's silver jubilee: Meeting the challenges and forging opportunities. *Restoration Ecology, 26*(1), 3-4. https://doi.org/10.1111/rec.12659

Nakagawa, S., Samarasinghe, G., Haddaway, N. R., Westgate, M. J., O'Dea, R. E., Noble, D. W. A., & Lagisz, M. (2019). Research weaving: Visualizing the future of research synthesis. *Trends in Ecology and Evolution, 34*(3), 224–238. https://doi.org/10.1016/j.tree.2018.11.007

Nugent, K., Strachan, I.B., Strack, M., Roulet, N.T., & Rochefort, L. (2018). Multi-year net ecosystem carbon balance of a restored peatland reveals a return to carbon sink. *Global Change Biology*, *24*(12), 5751–5768. https://doi.org/10.1111/gcb.14449

Nugent, K.A., Strachan, I.B., Roulet, N.T., Strack, M., Frolking, S., & Helbig, M. (2019). Prompt active restoration of peatlands substantially reduces climate impact. *Environmental Research Letters*, *14*(12), 124030.

O'Connor, C., & Joffe, H. (2020). Intercoder reliability in qualitative research: debates and practical guidelines. *International Journal of Qualitative Methods*, *19*, 1-13. https://doi.org/10.1177/1609406919899220

Parks Canada Agency. (2018a). *A natural priority – A report on Parks Canada's Conservation and Restoration Program*. Parks Canada Agency. https://www.pc.gc.ca/en/agence-agency/bib-lib/rapports-reports/core-2018

Parks Canada Agency. (2018b, June 7). *Overview – Parks Canada's Conservation and Restoration Program*. https://www.pc.gc.ca/en/agence-agency/bib-lib/rapports-reports/core-2018/apercu-overview

Parks Canada Agency. (2018c, December 28). *The Parks Canada mandate and charter – Parks Canada Agency*. https://www.pc.gc.ca/en/agence-agency/mandat-mandate

Parks Canada Agency. (2020, November 20). Get involved, build a legacy – Fundy National Park. https://www.pc.gc.ca/en/pn-np/nb/fundy/activ/decouverte-tours/benevolat-volunteering

Parks Canada & Canadian Parks Council. (2008). *Principles and guidelines for ecological restoration in Canada's protected natural areas*. https://www.pc.gc.ca/en/nature/science/conservation/ie-ei/re-er/pag-pel

Pellatt, M. G., & Gedalof, Z. (2014). Environmental change in Garry oak (*Quercus garryana*) ecosystems: The evolution of an eco-cultural landscape. *Biodiversity and Conservation*, *23*(8), 2053-2067. https://doi.org/10.1007/s10531-014-0703-9

Pouliot, K., Rochefort, L., LeBlanc, M-C., Guêné-Nanchen, N., & Beauchemin, A. (2021). The Burial Under Peat Technique: an innovative method to restore *Sphagnum* peatlands impacted by mineral linear disturbances. *Frontiers in Earth Science (Biogeoscience)*, *9*, 658470. https://doi.org/10.3389/feart.2021.658470

Quinty, F. & Rochefort, L. (1997). *Peatland restoration guide.* Canadian Sphagnum Peat Moss Association. Université Laval, Faculté des sciences de l'agriculture et de l'alimentation, Sainte-Foy, Canada. 21 pp.

Quinty, F. & Rochefort, L. (2003). *Peatland restoration guide, 2nd ed.* Canadian Sphagnum Peat Moss Association and New Brunswick Department of Natural Resources and Energy, Québec, Canada. 106 pp. https://www.gret-perg.ulaval.ca/uploads/tx_centrerecherche/Peatland_Restoration_guide_2ndEd.pdf

Quinty, F., LeBlanc, M-C. & Rochefort, L. (2019). *Peatland Restoration Guide – Plant Material Collecting and Donor Site Management.* PERG, CSPMA and APTHQ. Québec, Canada. 22 pp. https://tourbehorticole.com/wp-content/uploads/2020/03/Guide_restauration_tourbières_ANG_web.pdf

Quinty, F., LeBlanc, M-C. & Rochefort, L. (2020a). *Peatland restoration guide – Planning restoration projects.* PERG, CSPMA and APTHQ. Québec, Québec. 23 pp. https://tourbehorticole.com/wp-content/uploads/2020/10/Guide_4.1_Planning_Restoration_ANG_Web.pdf

Quinty, F., LeBlanc, M-C. & Rochefort, L. (2020b). *Peatland restoration guide – Site preparation and rewetting.* PERG, CSPMA and APTHQ. Québec, Québec. 23 pp. https://tourbehorticole.com/wp-content/uploads/2020/10/Guide_4.2_Site_Preparation_and_Rewetting_ANG.pdf

Quinty, F., LeBlanc, M-C. & Rochefort, L. (2020c). *Peatland restoration guide – Spreading of plant material, mulch and fertilizer.* PERG, CSPMA and APTHQ. Québec, Québec. 23 pp. https://tourbehorticole.com/wp-content/uploads/2020/10/Guide_4.4_Material_Spreading_ANG_Web.pdf.pdf

Shackelford, N., Hobbs, R. J., Burgar, J. M., Erickson, T. E., Fontaine, J. B., Laliberté, E., Ramalho, C.E., Perring, M.P., & Standish, R. J. (2013). Primed for change: developing ecological restoration for the 21st century. *Restoration Ecology*, *21*(3), 297-304. https://doi.org/10.1111/rec.12012

Society for Ecological Restoration International Science & Policy Working Group (2004). *The SER International Primer on Ecological Restoration.* Society for Ecological Restoration International. https://www.ser-rrc.org/resource/the-ser-international-primer-on/

Species at Risk Act, S. C. c. 29 (2002). https://laws-lois.justice.gc.ca/eng/acts/s-15.3/FullText.html

Strack, M. & Zuback, Y. (2013). Annual carbon balance of a peatland 10 yr. following restoration. *Biogeosciences*, *10*, 2885–2896. https://doi.org/10.5194/bg-10-2885-2013

Taylor, N., Price, J., & Strack, M. (2016). Hydrological controls on productivity of regenerating *Sphagnum* in a cutover peatland. *Ecohydrology*, *9*, 1017–1027. https://doi.org/10.1002/eco.1699

Turner N. J. (1999). ‘‘Time to burn’’: traditional use of fire to enhance resource production by aboriginal peoples in British Columbia. In Boyd, R. (ed.) *Indians, Fire, and the Land in the Pacific Northwest.* Oregon State University Press, Corvallis, pp 185–218.

Turner, N. J., Ignace, M. B., & Ignace, R. (2000). Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. *Ecological Applications*, *10*(5), 1275-1287. https://doi.org/10.1890/1051-0761(2000)010[1275:TEKAWO]2.0.CO;2

United Nations Environmental Program (UNEP) (2020). *The United Nations Decade on Ecosystem Restoration.* https://wedocs.unep.org/bitstream/handle/20.500.11822/31813/ERDStrat.pdf?sequence=1&isAllowed=y

Wortley, L., Hero, J. M., & Howes, M. (2013). Evaluating ecological restoration success: A review of the literature. *Restoration Ecology*, *21*(5), 537–543. https://doi.org/10.1111/rec.12028