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Research

The ecological success of river restoration in Newfoundland and Labrador, Canada: lessons learned

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ABSTRACT. Despite millions of dollars being spent annually to restore degraded river ecosystems, there exist relatively few assessments of the ecological effectiveness of projects. An evidence-based synthesis was conducted to describe river restoration activities in Newfoundland and Labrador. The synthesis identified 170 river restoration projects between 1949 and 2020. A practitioner's survey was conducted on a subset of 91 projects to evaluate ecological success. When the perceived success of managers was compared to an independent assessment of ecological success, 82% of respondents believe the projects to be completely or somewhat successful whereas only 41% of projects were evaluated as ecologically successful through an independent assessment. Only 11% of practitioners' evaluations used ecological indicators, yet managers of 66% of projects reported improvements in river ecosystems. This contradiction reveals a lack of the application of evidence to support value-based judgments by practitioners. Despite reporting that monitoring data were used in the assessment it is doubtful that any meaningful ecological assessment was conducted. If we are to improve the science of river restoration, projects must demonstrate evidence of ecological success to qualify as sound restoration. River restoration is a necessary tool to ensure the sustainability of river ecosystems. The assessment conducted in this study suggests that our approach to planning, designing, implementing, monitoring, and evaluating projects needs to improve. An integrated-systems view that gives attention to stakeholders' values and scientific information concerning the potential consequences of alternative restoration actions on key ecosystem indicators is required.

Key Words: *Canada, database, ecological, evaluation, monitoring, planning, river restoration*

INTRODUCTION

Environmental interventions are widely employed worldwide to mitigate impacts on river ecosystems (Roni et al. 2008, Gilvear et al. 2012, Angelopoulos et al. 2017). This global effort is expected to continue expanding in the coming decades to address societal challenges (Ladouceur and Shackelford 2021). Despite significant annual investments in restoring degraded river ecosystems (Bernhardt et al. 2005, Friberg et al. 2016, Angelopoulos et al. 2017), there is a lack of comprehensive national reviews or regional-scale data collection efforts to catalogue and evaluate the ecological effectiveness of these projects. In the United States, several reviews have examined practices at the national level (Bernhardt et al. 2005) and within specific regions (e.g., Alexander and Allen 2006, Alexander and Allen 2007, Rumps et al. 2007, Sudduth et al. 2007, Castillo et al. 2016). Similarly, in Europe, extensive reviews have been conducted on restoration efforts across the European Union (Angelopoulos et al. 2017). In contrast, Canada has not yet established a national repository or supported regional syntheses of restoration activities (King et al. 2022). Existing reviews of restoration practices in Canada have primarily focused on specific restoration strategies in certain regions (Scruton and Ledrew 1997, Mahlum et al. 2018) or specific applications in individual streams (van Zyll de Jong et al. 1997, van Zyll de Jong and Cowx 2016). Furthermore, the distinctive climatic regimes and characteristics of freshwater ecosystems in Canada's northern boreal forest limit the applicability of other regional restoration assessments and approaches (Kondolf 1998).

To advance the science of river restoration, efforts must be made to synthesize and understand restoration practices in Canadian rivers. Canada should adopt a systematic and standardized framework for assessment, like the approaches used in the United States and Europe. Whereas stream management efforts are coordinated at the federal level in the United States through the United States Geological Survey (USGS 2023) and through the European Union Water Directive in European countries (European Commission 2023), the responsibility for managing rivers in Canada is shared among federal, provincial, and municipal governments, and in some cases, by the territories and Indigenous governments under self-government agreements. This complex jurisdictional arrangement has resulted in the absence of a systematic approach. A well-curated and catalogued database would enable practitioners to gain better insights into the types of restoration techniques that have been applied (Bernhardt et al. 2005). Such a synthesis would facilitate the classification and categorization of projects, leading to an understanding of which project attributes worked, which did not, and why (Bernhardt et al. 2005, Ladouceur and Shackelford 2021). This represents a crucial initial step toward improving the science and practice of river restoration in Canada.

The following synthesis focuses on the province of Newfoundland and Labrador, where river restoration techniques have been implemented for the past seven decades (1949–2020). However, the lack of standardized reporting has made it challenging to describe restoration efforts in the province. This study aims to fill this knowledge gap by compiling and synthesizing information on restoration projects in Newfoundland and Labrador. The evidence-based synthesis will provide a representative summary database describing the nature and extent of river restoration activities, which can then be used for evaluation, research, and policy development. By comparing restoration outcomes across projects, researchers and practitioners will be able to develop best practices and establish a common understanding of ecological success.

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In summary, the objective of this study is to compile a comprehensive summary database of river restoration projects conducted in Newfoundland and Labrador over the past seven decades. This database will provide valuable information for evaluating and researching restoration efforts and informing policy development. Additionally, practitioners will be surveyed to assess the ecological effectiveness of these projects. By achieving these objectives, this study aims to advance the understanding and practice of river restoration in Canada by adopting systematic approaches that have been successfully implemented in the United States and Europe.

METHODS

Summary database development

A systematic review protocol was employed as the initial step to rigorously search for evidence of restoration projects. A comprehensive list of relevant search terms was generated and divided into four components (i.e., population, agents of change, intervention, and outcome) that were combined by using Boolean operations. The article databases recorded the search terms to preserve all associated metadata. The search encompassed various types of articles, including primary literature in peer-reviewed journals and gray literature. To minimize publication biases, equal efforts were directed toward each article type, and all articles underwent thorough critical appraisal to ensure validity. The publication databases used included Scopus, an abstract and citation database covering such peer-reviewed literature as journals, books, and conference proceedings; ProQuest Dissertations and Theses Global, an international repository of graduate dissertations and theses; and Waves (Fisheries and Oceans Canada), which includes Canadian government publications, reports, theses, conference proceedings, and journal titles. Additionally, search terms were entered into Google Scholar, and the first 1000 hits sorted by relevance were screened for suitability. Specialist organization websites were also searched by using specific search terms. Page data from the search results were extracted, screened for relevance, and searched for links or references to relevant publications and data in gray literature. After completing all searches and compiling the references found using each strategy, a list of 104 organizations in five group types (non-governmental organizations [NGOs], Indigenous groups, community development organizations, government, and academia) was created by narrowing down the websites. Furthermore, the reference sections of accepted articles, reports, and relevant reviews were manually searched to identify additional titles, symposium papers, and articles that were not found through the search strategy. Email messages were utilized to notify the community about this systematic review and to reach out to practitioners and experts for hard-to-obtain research articles or suggestions for inclusion. After completing the searches and compiling the references, individual databases were exported into Excel as one comprehensive database. Duplicates were identified and merged. All references, regardless of their perceived relevance to the systematic review, were included in the Newfoundland and Labrador River Restoration Database (NLRRD), resulting in a total of 170 stream restoration projects with sufficient data to understand the current state of restoration in Newfoundland and Labrador. The database included group type, organization, National River Restoration Science Synthesis (NRRSS) category (Table 1), project intent, title, location, year started, duration, total cost, source, and contact information.

Interview database development

Extensive efforts were made to contact all groups associated with the 170 projects. Only projects that could be represented by a contact person or project manager with sufficient knowledge to answer the survey were considered eligible for interviews. Eligible projects were selected on the basis of their alignment with selected NRRSS categories (Table 1) that aimed to improve the ecological conditions of the river (e.g., bank stabilization, channel reconfiguration, dam removal/retrofit, fish passage, flow modification, in-stream habitat improvement, in-stream species improvement, riparian management, and water quality). All eligible projects were included in the interview database. A practitioner survey, originally developed by Palmer et al. (2005), was used for the interviews. The survey, provided by the author, underwent a slight modification to incorporate questions related to climate change considerations in project planning, implementation, and monitoring. The survey mechanism was designed on the basis of best practices in social science research (Palmer et al. 2005). The survey aimed to explore the role of science in restoration, assess the extent and type of project evaluation, evaluate the success of the projects, and identify key lessons. The survey was administered through a virtual workshop conducted via WebEx. An interactive, real-time survey created on Poll Everywhere was shared with the participants through an internet link or text message. Each survey took approximately 30 min to complete.

Interview database analysis

Descriptive statistics were employed to analyze all survey data. In addition to basic descriptive statistics, the survey was used to evaluate the ecological effectiveness of the projects. The evaluation categorized survey questions according to the criteria defined by Palmer et al. (2005), including (1) having a guiding image, (2) completing an ecological assessment, and (3) demonstrating ecological improvements. The remaining two criteria, (4) not causing lasting harm and (5) increasing ecosystem resilience, were deemed impossible to evaluate. The assessment of the guiding image was based on such factors as whether an assessment was conducted, whether the project was part of an existing watershed management plan, and whether ecological impacts were considered in determining the final project design with stated success criteria (Alexander and Allen 2007). The evaluation of ecological assessment examined the presence of monitoring variables for assessing success, the use of baseline conditions as a guide, the analysis of monitoring data for evaluating project success, and the utilization of specific ecological indicators to determine success.

RESULTS

Summary database

The summary database is composed of a total of 170 stream restoration projects, providing insights into the current state of river restoration in Newfoundland and Labrador. The data sources utilized include academic institutions, community development groups, Indigenous groups, NGOs, and government

Table 1. National River Restoration Science Synthesis (NRRSS) working group list of goal categories and operational definitions. Those used in the current study are described.

Goal categories	Operational definitions
Bank stabilization	Practices designed to reduce/eliminate erosion or slumping of bank material into the river channel.
Flow modification	Practices that alter the timing and delivery of water quantity.
Channel reconfiguration	Alteration of channel plan form or longitudinal profile. Includes stream meander restoration and in-channel structures that alter the thalweg of the stream. Note that many in-stream structures also claim to improve habitat. For NRRSS the intent declared in the source document must be used.
Fish passage	Removal of barriers to upstream/downstream migration of fishes. Includes the physical removal of barriers and construction of alternative pathways. Includes migration barriers placed at strategic locations along streams to prevent undesirable species from accessing upstream areas.
Riparian management	Revegetation of riparian zone and/or removal of exotic species (e.g., weeds, cattle). Excludes localized planting only to stabilize bank areas (see *bank stabilization*).
In-stream species management	Practices that directly alter aquatic native species distribution and abundance through the addition (stocking) or translocation of animal and plant species and/or removal of exotics. Excludes physical manipulations of habitat/breeding territory (see *in-stream habitat improvement*).
Dam removal/retrofit	Removal of dams and weirs or modifications/retrofits to existing dams to reduce negative ecological impacts. Excludes dam modifications that are simply for improving *fish passage*.
In-stream habitat improvement	Altering structural complexity to increase habitat availability and diversity for target organisms and provision of breeding habitat and refugia from disturbance and predation. In some cases, habitat improvement may be an action with the intent of *in-stream species management*, in other cases *habitat improvement* may be the intent, and might be accomplished through *channel reconfiguration*; be very careful to separate action from intent when deciding whether to select this category.
Aesthetics/recreation/education	Activities that increase community value: use, appearance, access, safety, knowledge.
Water quality management	Practices that protect existing water quality or change the chemical composition and/or suspended particulate load.

entities (Table 2). According to the National River Restoration Science Synthesis (NRRSS) definitions, the projects were categorized on the basis of their intent. The breakdown of project types in the summary database was as follows: fish passage (35%), in-stream habitat improvement (25%), dam removal/retrofit (15%), aesthetics (13%), bank stabilization (7%), in-stream species management (4%), water quality (1%), and riparian management (1%; Fig. 1). This distribution differs somewhat from that reported by Bernhardt et al. (2005), who found that water quality and riparian management projects constituted most of their database (almost two-thirds of projects), with in-stream habitat improvement projects comprising 16%. The cost information was available for 90% of the projects, totaling $27.5 million over the seven decades. The cost of projects ranged from $2965 to $3,600,000, with a mean cost of $199,456 (Fig. 2).

Table 2. Group types, number of groups, and number of projects in the summary database.

Group type	Number of groups	Number of projects
Community	29	87
Non-profit	6	25
Government	4	45
Indigenous	2	6
Academic	2	7

Interview database

Because of difficulties in identifying contact persons or program managers for projects before 1980, only restoration projects from the last four decades were included in the interview database. Out of the 170 projects in the summary database, 91 projects, representing 54%, were selected for interviews. The interview database covered various project categories, including fish passage (36%), in-stream habitat improvement (22%), in-stream species management (16%), dam removal/retrofit (11%), bank stabilization (4%), water quality (4%), flow modification (3%), and riparian management (2%; Fig. 3). The distribution of project types in the interview database mirrored that of the summary database. Among the practitioner groups included in the interviews, non-governmental organizations accounted for the largest proportion of projects, followed by government-run projects, and privately or voluntarily implemented projects with stakeholder assistance. However, Indigenous groups were not represented in the interview database. The projects in the interview database were, on average, more recent than those in the summary database, with a median completion date of 1980–2019 for the interview database compared to 1949–2019 for the summary database. The costs of the projects in the interview database ranged from $6000 to $1,600,000, with a mean cost of $243,825 (Fig. 4). Funding sources for the projects included the federal government (32%), non-governmental organizations (29%), in-kind volunteer contributions (17%), provincial government (10%), and municipal government (10%). Project selection was primarily motivated by funding priorities (26%), management plans (20%), NGO-led initiatives and stakeholder opinion (16% each), and regulatory and mitigation requirements (10% and 5%, respectively). Most projects were conducted on crown lands (63%), followed by municipal lands (19%), federal lands (11%), and private lands (7%).

Project design, implementation, and coordination

The interviews revealed that 61% of the projects were part of a watershed plan, with varying degrees of overlap between project goals and management plans. Surprisingly, only 6% of respondents considered watershed plans as important factors in project site selection. Cost and past experiences were cited as the primary influences on final project design, with stakeholders and

Fig. 1. Summary database project types by NRRSS categories: 1, fish passage; 2, in-stream habitat improvement; 3, in-stream species management; 4, dam removal/retrofit; 5, bank stabilization; 6, water quality; 7, flow modification; 8, riparian management.

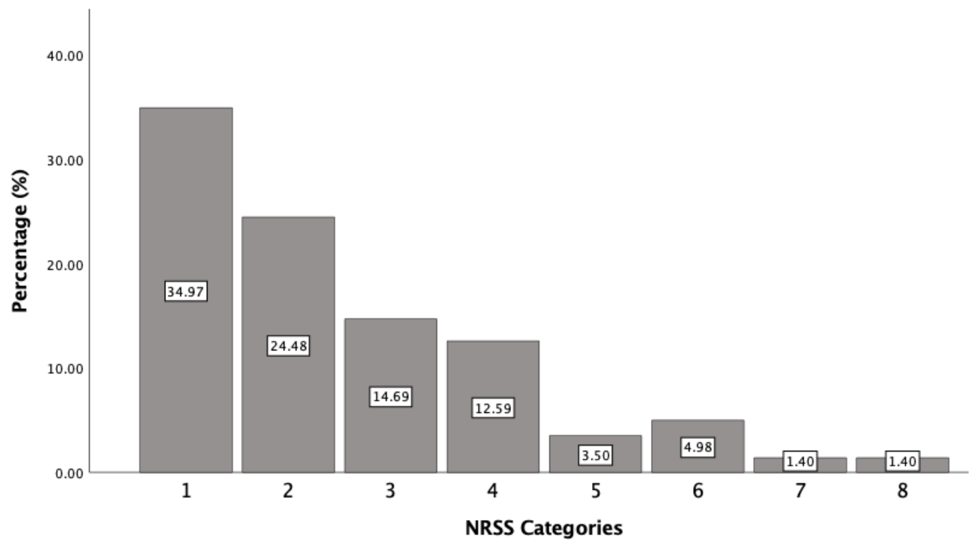
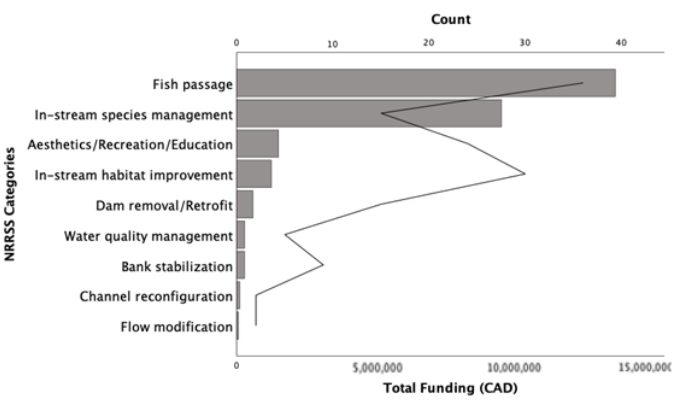


Fig. 2. Total cost (millions of CAD$) and the number of stream and river restoration projects in Newfoundland and Labrador by project type for the summary database.



project location also playing a role (Fig. 5). When asked about the influence of climate change considerations on project design, 82% of practitioners stated that climate change was not considered, whereas 18% incorporated climate change considerations. Funding, ecological concerns, and public demand were identified as the main factors driving the rationale behind the final project design, with funding being the most prominent factor (33%) followed by ecological concerns (23%) and public demand (13%). Stakeholder experience and how-to manuals (26%), peer-reviewed literature (20%), modeling (16%), and stakeholder or expert opinion (12%) were the most frequently-used tools and resources for project design. Initial design workshops were conducted for 56% of projects, and advisory groups were established for 38% of projects. A total of 71% of projects indicated that data collection for design, implementation, and evaluation purposes was part of their objectives.

Project monitoring

Among the surveyed projects, 55% reported collecting monitoring data for evaluating project success. Of the monitoring approaches used, 49% followed established protocols from federal, provincial, or other sources; 22% relied on expert opinion; 20% used project-specific monitoring based on books or manuals; and 9% did not specify a specific approach (Fig. 6). Monitoring activities were carried out by academics (38%), NGO experts (28%), government agencies (15%), volunteers (9%), and consultants (3%). The types of monitoring conducted included biological (29%), visual assessment with geomatics or photomapping (26%), physical (26%), and chemical (9%). Only a small percentage of projects (23%) conducted qualitative assessments to identify climate change risks and vulnerabilities, such as flow and temperature changes, exotic species' presence, and threats to key habitats.

Project evaluation

Of the surveyed projects, 20% reported implementing the projects as originally designed, whereas 90% stated that implementation was somewhat close to the original design. Regarding project evaluation, 47% of projects conducted some analysis of monitoring data, and the same percentage indicated that success criteria were stated in the design plan. Among the projects that evaluated success based of these criteria, 30% used statistical methods, 30% employed a comparative evaluation approach, 18% utilized modeling, and 15% used graphical approaches. However, 7% of projects did not report the means of evaluation. Of the projects that were evaluated by using success criteria, only 18% were considered successful, 36% were partially successful, 27% were deemed somewhat successful, and 13% were not successful. When asked about the overall success of their projects, 18% of

Fig. 3. Interview database projects by NRRSS categories: 1, fish passage; 2, in-stream habitat improvement; 3, in-stream species management; 4, dam removal/retrofit; 5, bank stabilization; 6, water quality; 7, flow modification; 8, riparian management.

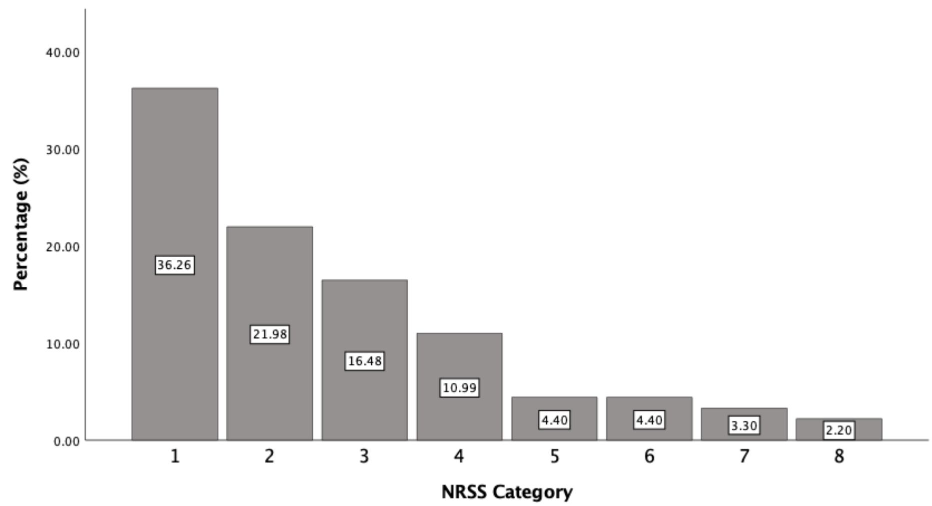


Fig. 4. Total cost (millions of CAD$) and the number of stream and river restoration projects in Newfoundland and Labrador by project type for the interview database.

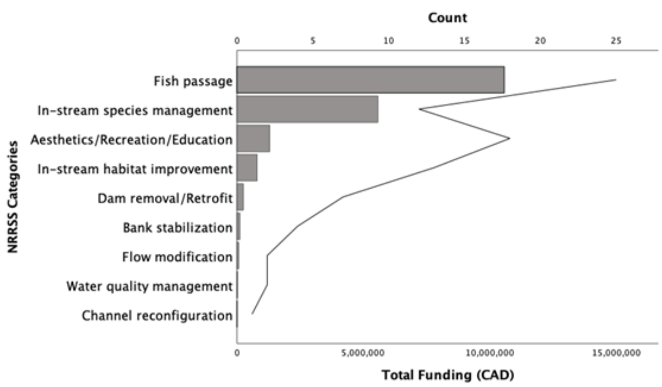
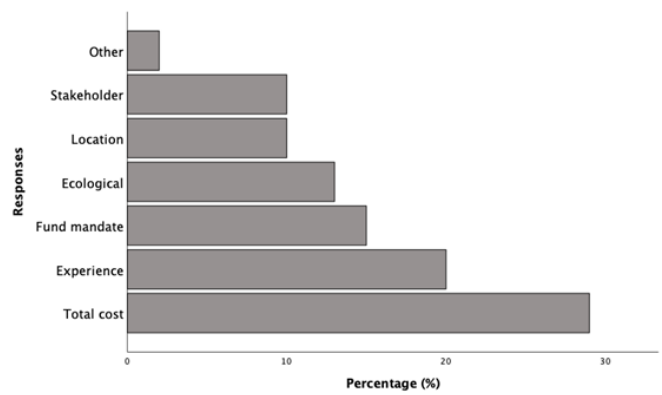


Fig. 5. What factors motivated the final design of projects?



respondents claimed their projects were completely successful, 36% viewed them as nearly completely successful, 27% considered them somewhat successful, 14% perceived little success, and 5% believed it was too early to determine success. The factors identified by project practitioners that contributed to project success were as follows: understanding the ecosystem (31%), human interaction (17%), river improvement (17%), capacity building (15%), ecosystem services (11%), wildlife improvement (7%), and indicator improvement (2%; Fig. 7). Additionally, project success was associated with such benefits as partnerships (26%), increased awareness (26%), improvement in ecosystem services (20%), capacity building (12%), and contributions to scientific literature (12%). On the other hand, factors identified as obstacles to success included inadequate funding (25%), natural flood disturbances (21%), human disturbances (10%), poor implementation (10%), and structural failures (10%; Fig. 8).

Ecological success

To assess the ecological effects of the projects, we categorized key survey questions based on the framework established by Palmer et al. (2005) and used the approach described by Alexander and Allen (2007). We calculated the average score based on the selected questions to determine ecological success. Regarding the presence of a guiding image, indicating whether projects had a clear vision or goal, 39% of projects met this criterion. To evaluate whether projects measured improvement in river ecosystems, we examined the extent to which success criteria were met and whether positive changes were detected in monitoring variables. Based on this evaluation, 31% of projects achieved this criterion. To assess the completion of an ecological assessment, we analyzed responses to six interview questions related to the monitoring or evaluation of ecological indicators. This criterion was successfully met by 54% of projects. Considering all three criteria collectively, many projects did not fulfill the necessary requirements to be ecologically successful (Table 3).

Fig. 6. What factors enabled monitoring?

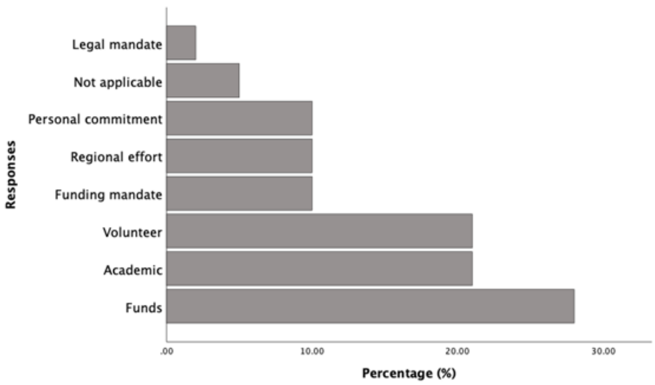


Fig. 7. What factors drove project success?

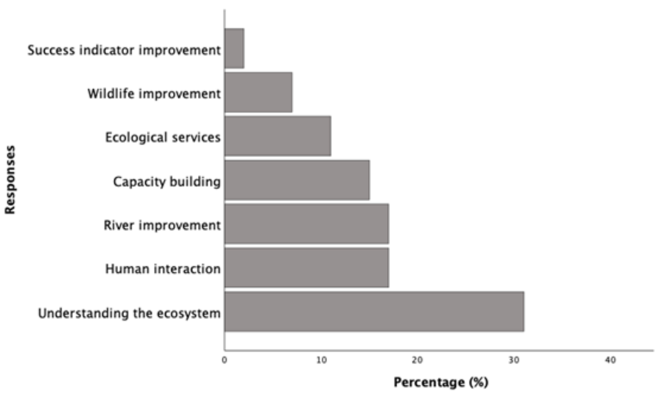
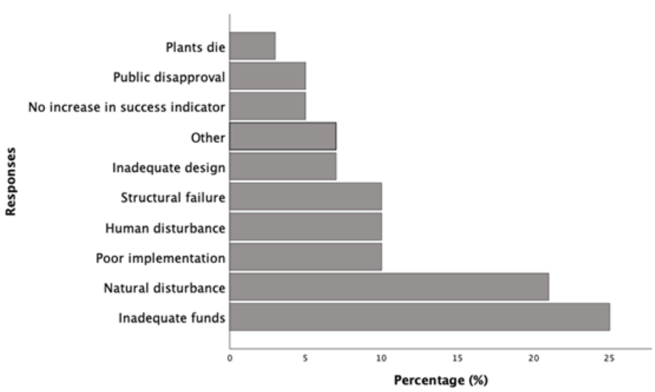


Fig. 8. What factors were responsible for project failure?



DISCUSSION

The study provided an accurate representation of river restoration projects in Newfoundland and Labrador and defined key insights in assessing the ecological success of projects. The summary database was compiled initially through a rigorous systematic review protocol, providing evidence of 170 regional representative projects over the last seven decades (Palmer et al. 2005). Project inventories were examined and verified by regional practitioners and regional experts. In Newfoundland and Labrador, all river restoration activities are publicly funded through either direct government funding programs or registered NGOs. Before this effort, there existed no centralized project repository. What became evident in the search for projects was that, in general, groups tracked projects and recorded outcomes. However, groups did not follow a standard reporting framework, and in many cases, projects were missing key details, such as project title, contact, timeline, and funding sources. In terms of the total of 273 projects discovered, 170 projects had completed verifiable information. In the future, a framework for project management that includes proper design and reporting will allow us to begin to build a valuable database to inform best practices and policies.

Of the 40 groups that have historically conducted restoration projects, 11 groups were interviewed. In many cases, the groups had become defunct, and in other cases, they did not respond to interview requests, even after multiple attempts at communication. The result of these constraints was that all projects in the interview database were from 1980 to the present. Historical projects before 1980 were not used in the practitioner's survey. As a result, our sample was biased toward established, larger, and more recent groups. Despite this constraint, the interview database did provide an excellent representation of project type, geographic distribution, and type of organization. The research project used a modified survey created by Palmer et al. (2005). The modified version added questions about climate change, although the rest of the survey remained the same. The step-by-step guide aided in our data collection via an online survey with experts. Although different from Palmer's approach, this strategy was successful in gathering essential data in a pandemic era. Analysis of the results concluded that restoration projects in Newfoundland and Labrador were not based mainly on ecological indicators. Motivations of project design were mainly focused on access to funding. The analysis presented can be considered a stepping stone for future projects to determine a more systematic and structured approach for the evaluation of project success. Future studies can work on delineating which factors (economic, political, or social) contributed most to project design.

When comparing the perceived success reported by practitioners to our assessment of ecological success based on responses to survey questions, the difference between perception and reality is apparent. The survey revealed that over 82% of respondents believe the projects to be completely or somewhat successful. Our evaluation suggests that only 41% were ecologically successful. Based on the three criteria (see Table 3), only 39% of projects used a guiding image, 31% of projects showed measurable ecosystem improvement, and 54% did an ecological assessment, with only 11% basing the assessment on ecological indicators. Most projects

Table 3. Evaluation of ecological success based on three criteria based on interview questions.

Criteria	Responses
Guiding image exists	
A watershed assessment was completed	35
Project was part of a watershed management plan	61
Ecological impacts determined final project design	14
Success criteria were stated	47
Ecosystem was measurably improved	
Success criteria were met	
Completely	21
Partially	15
Monitoring variables showed a	
Positive response	18
Too soon to tell	4
The project had positive effects on	
River improvement	17
Wildlife improvement	7
Ecosystem services	11
An ecological assessment was completed	
Variables were monitored	
Before	57
After	55
Control/reference	57
Baseline conditions were monitored	57
Monitoring data were analyzed	75
Analysis of monitoring data was disseminated	67
Monitoring data were used to evaluate the project	55
Ecological indicators showed project success	11

reported success based on human benefits, such as capacity building, better collaboration, and understanding of ecosystem function, rather than actual ecosystem improvement. Only 16% reported river improvement, 11% reported ecosystem service improvements, and only 2% reported that success was determined by an indicator of improvement. Proper monitoring of key indicators is essential for meaningful evaluation.

In this study, 55% of projects reported that monitoring data were used to evaluate success. Of these projects, only 11% used ecological indicators, yet project managers reported that 66% of projects reported improvements in understanding ecosystem dynamics, river function, ecosystem services, and wildlife. This shows the lack of application of evidence to support value-based judgments by practitioners. Despite the high level of reporting that monitoring data were used in the assessment, it is doubtful that any meaningful ecological assessment was conducted. The survey also revealed that 88% of projects did not include climate change vulnerability or risk in the design or assessment of projects. In addition to agents of change, such as climate, little to no attention was given to landscape-level factors in the design, monitoring, or implementation of projects, with only 31% using a guiding image.

Many projects expressed the lack of funding and short-term project planning as deterrents to monitoring. Typically, funding is available only for the duration of project implementation and does not allow for the necessary pre-and post-monitoring required to detect changes in ecosystem attributes. In addition to a lack of time and funding for monitoring, long-term maintenance of project elements is also lacking, with only half of the projects conducting follow-up maintenance. For restoration efforts to be ecologically successful over time, maintenance is essential. Very few long-term studies examine the long-term effects of different restoration approaches on rivers (Thompson and Stull 2002, Whiteway et al. 2010, van Zyll de Jong and Cowx 2016). In all cases, success was a function of design, the presence of pre- and post-monitoring, rigorous scientific evaluations, and long-term maintenance of physical structures (Palmer et al. 2005).

CONCLUSION AND RECOMMENDATIONS

River restoration is a necessary tool to ensure the sustainability of river ecosystems. The assessment conducted in this study suggests that our approach to planning, designing, implementing, monitoring, and evaluating projects needs to improve. An integrated-systems view that gives attention to both stakeholder values and scientific information concerning the potential consequences of alternative restoration actions on key ecosystem indicators is required (Cowx and van Zyll de Jong 2004, King et al. 2022). An explicit, value-laden, decision-driven approach based on the best available information is required that links values to facts (Kondolf et al. 2001, Downs and Kondolf 2002, Gregory et al. 2012). If the practice of river restoration is to improve, project designs must be able to demonstrate evidence of ecological success to qualify as sound restoration (Palmer et al. 2005). A framework is needed that enables scientists, managers, and local watershed stakeholders to better understand the connections between physical processes and aquatic habitat, and to acknowledge and understand the connections between representative data, river processes, evaluation of key attributes, change scenarios, impacts of change, and trade-off and decision making in the planning and design process. Additionally, it is crucial to become aware of restoration design alternatives that can minimize risks to species and habitats, provide project monitoring and evaluation, and foster consistent reporting. Furthermore, promoting best practices for effective future river management and enhancing the dissemination of findings and access to historical data will contribute to the improvement of river restoration efforts. Stronger emphasis is also needed on understanding the role and magnitude of physical river processes and how these are mechanisms of habitat creation (Beechie et al. 2010, Ciotti et al. 2021). By addressing these recommendations, the science of river restoration can advance and contribute to the sustainability of river ecosystems.

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Data Availability:

The database is available upon request by the authors.

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