SOCIO-ECOLOGICAL LINKAGES

Building Resilience in Ecological Restoration Processes: A Social-Ecological Perspective

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ABSTRACT

Ecological restoration is a means of addressing the ongoing and pervasive degradation of ecological systems. Although the aim of ecological restoration is ecosystem recovery, efforts based on an oversimplified understanding of how complex adaptive systems behave often fail to produce intended outcomes. We explore how advancements made in understanding properties of complex adaptive systems, specifically social-ecological systems, may be incorporated into ecological restoration. We present a conceptual framework informed by tracing the evolution of perspectives in ecological restoration and synthesizing developments in social-ecological resilience. We then employ the framework in the context of freshwater systems to assess Trout Unlimited Canada's stream rehabilitation training program and evaluate associated restoration initiatives in terms of social-ecological resilience. Findings from this case study indicate that the approach to restoration taught in the training program, along with the initiatives informed by the program, reflect principles for building resilience and were found to be positive. These findings provide encouraging evidence in support of a new approach to restoration informed by social-ecological resilience and initial confirmation of the usefulness of the framework. Valuable insights on the extent to which social-ecological resilience is currently reflected in restoration practices more broadly will come from future research exploring the application of the conceptual framework in a variety of restoration contexts and at a larger scale.

Keywords: complex adaptive systems, resilience practice, resilience, restoration framework, stream rehabilitation, Trout Unlimited Canada

Restoration Recap

- Ecological systems around the world have been, and continue to be, negatively altered. Restoring these systems and the ecosystem services they provide is a worthwhile goal. However, not all restoration initiatives are successful. Restoration based on oversimplified understandings of these systems tends to result in failure.
- Taking an approach to restoration that reflects the current state of knowledge on these systems may help overcome these failures. One such approach is undertaking restoration informed by social-ecological resilience.
- Applying the principles for building resilience in social-ecological systems to the restoration process presents an opportunity to improve restoration outcomes and their evaluation.
- Testing this new approach in practice and in different restoration contexts is an important next step to understand whether it results in positive social and ecological restoration outcomes and to learn from those experiences.

Ecological restoration offers hope for recovery from ecosystem impairment and the threats facing ecosystems. With the common aim of assisting the recovery of systems, ecological restoration encompasses a broad range of activities from local to regional initiatives, one-off projects to multi-year programs, volunteer efforts to large-scale multi-agency endeavours, and passive and active abiotic and biotic interventions (Hobbs and Cramer 2008, Perring et al. 2015). Societal demand for ecological restoration is growing with increasing recognition of the full extent of potential benefits associated with restoration (Gann and Lamb 2006, Suding 2011, Perring et al. 2015). As described by Palmer et al. (2006), billions of dollars are spent each year attempting to restore "polluted and sediment-clogged streams" and "reforest lands that have been degraded and fragmented".

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Although undertaken with the best of intentions, attempts at ecological restoration can fail to produce intended results, or even exacerbate problems when based on oversimplified understandings of a system (Hobbs and Norton 1996, Lake et al. 2007). Restoration projects, premised on the assumption that it is possible to create or restore an ecosystem that provides a specific set of services and functions, have mixed results (Bendor 2009, Moilanen et al. 2009, Suding 2011). Changes in land use, biodiversity, and climatic conditions have made it impossible for an ecosystem to return to its previous state in terms of exact structure or composition, despite a heavy reliance on engineered solutions (Zellmer and Gunderson 2008, Hobbs et al. 2011, Suding 2011, Perring et al. 2015). A fixation on treating symptoms, as opposed to causes of ecosystem degradation, has also been cited as contributing to non-recovery. In synthesizing the many reasons restoration projects fail, Hilderbrand et al. (2005) draw attention to "myths of restoration." Central among these myths is the reduction of complex systems to a point at which simplified guiding principles can be applied universally with little understanding or consideration of uncertainty, surprise, interconnections, and temporal and spatial scales. Hobbs and Cramer (2008) regard moving beyond the myths of restoration as being critical to the development of more effective restoration strategies.

Social-ecological resilience, as an emergent scholarly area, captures advancements made in understanding properties of complex adaptive systems (CAS [e.g., uncertainty, nonlinearity, cross-scale interactions]) as well as linkages between social and ecological systems (Folke 2006, Plummer 2010). Incorporating resilience concepts into ecological restoration has been put forward as a means of moving away from restoration based on oversimplified understandings of systems. However, exactly how resilience might be incorporated into ecological restoration is an area in need of further exploration (Suding 2011, Hallett et al. 2013).

We tackle the question of how social-ecological resilience may be incorporated into ecological restoration and then focus specifically on the context of freshwater systems. To explore this question, we trace how perspectives in ecological restoration are changing and synthesize pertinent scholarship on social-ecological resilience. Intersections between these two areas of scholarship are rich and provide the basis to develop a framework which conceptually advances how resilience may be incorporated into ecological restoration. Following a description of this framework, we employ it in the context of freshwater systems by using it to assess Trout Unlimited Canada's stream rehabilitation training program and evaluate restoration initiatives informed by the training program in terms of social-ecological resilience.

Evolution of Perspectives in Ecological Restoration

Perspectives on ecological restoration are not static. Much has changed, and continues to change, in terms of how ecosystems are understood, which activities are considered under the term "restoration," how goals are defined, and how success is measured (Perring et al. 2015). This evolution of perspectives is to be expected as restoration ecology matures as a science and as knowledge of ecosystem dynamics advances (Suding 2011). Three broad perspectives are described here.

The first perspective on ecological restoration is emulating historic conditions. This perspective assumes that an ecosystem will return to a more "natural" or "pristine" state, functioning in a manner similar to its pre-impairment condition (Hobbs and Harris 2001, Suding et al. 2004, Hilderbrand et al. 2005, Hobbs and Cramer 2008, Perring et al. 2015). It is based on the notion that it is possible to replicate a specific combination of ecosystem conditions (Hobbs and Harris 2001, Hobbs and Cramer 2008).

An alternative perspective of ecological restoration gives greater consideration to the dynamic nature of ecosystems and acknowledges complexity (Hobbs and Norton 1996, Choi 2007, Suding 2011, Perring et al. 2015). Proposed aims informed by this perspective are all closely related and include restoration of ecosystem functions and/or processes (Harris et al. 2006, Hobbs and Cramer 2008, Beechie et al. 2010, Perring et al. 2015), desirable ecological goods and services (Bullock et al. 2011, Nellemann and Corcoran 2010, Suding 2011, Perring et al. 2015), ecological integrity (Jungwirth et al. 2002, DellaSala et al. 2003, Parks Canada 2008), and resilience (Carpenter and Cottingham 1997, Zellmer and Gunderson 2008, Suding 2011, Wilson and Browning 2012, Perring et al. 2015). Referred to as "Restoration v2.0" by Perring et al. (2015), this perspective supports the view that ecological restoration is a complex endeavour and should involve the consideration of an ecosystem's unique past, its specific spatial setting with consideration of larger and smaller scales, and current and future drivers of change (Pickett and Parker 1994, Hobbs and Norton 1996, Zellmer and Gunderson 2008, Jackson and Hobbs 2009, Galatowitsch 2012, Suding et al. 2015).

Impetus for a third, resilience-based perspective, is given by the realities of unpredictable successional processes (Pickett and Parker 1994, Hobbs and Norton 1996, Suding et al. 2004, Choi 2007), multiple alternative stable states (Pickett and Parker 1994, Young et al. 2001, Suding and Gross 2006, Choi 2007, Jackson and Hobbs 2009), nonlinear and threshold responses to disturbances (Hobbs and Norton 1996, Lindenmayer et al. 2008, Suding and Hobbs 2009, Perring et al. 2015), and the ecological legacies left by human activities (Hobbs and Harris 2001, Jackson and Hobbs 2009, Allison 2012). More specifically, increasing calls for social considerations to be taken into account in ecological restoration (e.g., Choi 2007, Zellmer and Gunderson 2008, Bliss and Fischer 2011, Naiman 2013, Abelson et al. 2015, Perring et al. 2015, McDonald et al. 2016, Wantzen et al. 2016) validate a perspective informed by social-ecological resilience. This perspective recognizes that ecosystems are continuously evolving in response to external influences as well as endogenous processes (Vitousek et al. 1997, Sanderson et al. 2002, Clewell and Aronson 2013). Of course, restoration is inherently anthropocentric, and as such, it can be argued that at least some social considerations are taken into account in every project. However, this perspective goes further to include a wider range of social considerations and emphasizes interactions of the ecological system with the social system and influences from it and on it.

The Emergence of Social-Ecological Resilience in Thinking and Practice

In the time since Holling's (1973) seminal work on ecological resilience, the number of scholarly articles and books on the topic of resilience continues to grow significantly, particularly in the context of social-ecological systems (SES [Janssen 2007, Xu and Marinova 2013]). This growth has been fueled by the nature of the real-world problems facing the global community (Beichler et al. 2014). Contemporary challenges are complex, they are not simply social issues or ecological problems, and they cannot be solved with panaceas (Ostrom 2007, 2009). As stated by Ostrom (2007), "moving beyond panaceas to develop cumulative capacities to diagnose the problems and potentialities of linked SESs requires serious study of the complex, multivariable, nonlinear, cross-scale, and changing SESs". In order to explore, research, or attempt to find solutions to contemporary problems, a framework or way of thinking that is capable of capturing the complexities associated with these problems is necessary, and social-ecological resilience approaches are an evolving solution (Deppisch and Hasibovic 2013).

Efforts are evident to summarize the state of knowledge on resilience with regard to complex SES. Folke et al. (2003) identify four critical factors for building resilience for adaptive capacity: 1) learning to live with change and uncertainty; 2) nurturing diversity for reorganization and renewal; 3) combining different types of knowledge for learning; and 4) creating opportunity for self-organization.

A second example is Biggs et al.'s (2012) seven principles for building resilience of ecosystem services. This set of principles is particularly well suited to the exploration of ecological restoration informed by social-ecological resilience for several reasons. These seven generic principles are purportedly applicable to SES broadly and were developed based on an assessment of the resilience literature, a modified Delphi survey of leading resilience experts, and a mock court workshop (Biggs et al. 2012). Accordingly, the principles represent the current state of knowledge required for building resilience and have been widely cited in the resilience literature. A brief description of each of the seven principles is provided in Table 1. The first three principles listed in Table 1 focus on generic SES properties and processes to be managed, while the remaining four principles relate to key properties of SES governance (Biggs et al. 2012). Despite these groupings, the authors stress that the seven principles are often highly interdependent (Biggs et al. 2012).

The need to transition from resilience thinking to resilience practice in real world situations, and the challenges associated with this task, have been referred to many times in the scholarly literature on the subject (Peterson 2002, Cumming et al. 2005, Miller et al. 2010, Walker and Salt 2012, Plummer et al. 2014). Miller et al. (2010) argue that one of several reasons why this transition is so difficult is because of a limited amount of detailed guidance on how to actually undertake actions to build resilience. At the same time, these authors acknowledge the danger in detailed manuals or "cookbooks" for governing complex SES. Evidently, a balance must be struck between providing guidelines that are specific enough to assist practitioners in answering questions and offering guidance that is flexible enough to appreciate the great deal of variation within and across SES (Miller et al. 2010).

Limited examples exist of applying resilience thinking in practice in relation to ecological restoration (see for example Wantzen et al. 2016). Parks Canada's (2008) guide to ecological restoration in Canada's protected natural areas is one example as its planning and implementation process is based on guidelines for restoration that are influenced by resilience thinking. Another noteworthy example is the European Union's Water Framework Directive (WFD) which "shifts the focus of river restoration towards projects aimed at improving the aquatic ecosystem more generally rather than simply habitat enhancement for a single species" (Smith et al. 2014; p. 254). The WFD also requires public participation in restoration, however, Gregory et al. (2011) point out that because the overall goals of the legislation are already decided, local stakeholders actually have limited ability to influence the decision-making process.

Albeit there are limited examples in the ecosystem restoration scholarship, resilience thinking is being incorporated in related fields. Benson and Garmestani (2011), for example, detail how natural resource managers are beginning to invoke the concept of resilience, while Fischer et al. (2009) explore how resilience thinking and optimisation may be brought together for improved conservation strategies. Similarly, Tyler and Moench (2012, 311) developed an operational framework for urban planning practitioners in 10 cities across Asia that "integrates theoretical and empirical knowledge of the factors contributing to resilience with processes for translating those concepts into practice".

Table 1. Principles for building resilience in SES (adapted from Biggs et al. 2012).

1. Maintain diversity and redundancy When confronted with disturbance, the existence of functional redundancy means that, while some components of the system may be lost, those that remain compensate for the loss. When components within the same functional group exhibit diversity in their response to a certain disturbance, redundancy is considered even more valuable. Diversity and redundancy provide options for responding to change and confronting uncertainty, thereby building resilience.
2. Manage connectivity Connectivity in SES refers to both the nature and strength of interactions between system components. Connectivity can positively or negatively influence a system. High connectivity is considered to be important in aiding recovery following a disturbance but disturbance also spreads faster in highly connected systems. Therefore, the key is managing an appropriate level of connectivity given the specific context of the system.
3. Manage slow variables and feedbacks Managing slowly changing variables and positive and negative feedbacks that influence the configuration of a system is critical to avoid crossing a threshold. Feedbacks that maintain desirable system configurations should be strengthened and the key slow variables should be monitored for their proximity to thresholds. Additionally, governance structures capable of effectively responding to monitoring data must be established.
4. Foster CAS thinking Although fostering CAS thinking may not directly enhance the resilience of a system, it does contribute to building it. Considering SES as CAS requires disengaging from steady-state reductionist thinking and accepting unpredictability, uncertainty, and variability. Changing how complex systems are understood is the first step in altering behaviour in favour of practices that build resilience.
5. Encourage learning and experimentation Uncertainty and the dynamic nature of complex SES require that learning remain an ongoing part of managing a system to enhance resilience. Potential mechanisms for encouraging learning and experimentation include adaptive management, adaptive co-management, and adaptive governance. Also highlighted in these approaches is the importance of knowledge sharing among actors and across scales.
6. Broaden participation Engaging relevant stakeholders in the management of SES builds resilience by bringing together diverse types and sources of knowledge. Stakeholder engagement enhances capacity for collective action through building a shared understanding and improving trust and legitimacy. However, participation of all relevant stakeholders in all stages of management is not always feasible or desirable. Broad participation is particularly useful when management needs and priorities are being debated and determined.
7. Promote polycentric governance systems Polycentric governance helps ensure that problems are addressed at the appropriate scale, by the right individuals. Polycentric governance enhances resilience by improving connectivity, creating modularity, enabling broader levels of participation and providing opportunities for learning and experimentation, improving potential for response diversity, and by building redundancy that can minimize and correct governance errors.

A Framework to Incorporate Resilience Thinking in Ecological Restoration

Evolving perspectives in ecological restoration and scholarship on social-ecological resilience drove our development of a framework for how the ecological restoration process and generic principles for building resilience may conceptually come together (Table 2). The five general phases, or common steps, of ecological restoration process were derived from several sets of guidelines established for ecological restoration initiatives (see for example Daigle and Havinga 1996, OMNR and Watershed Science Centre 2002, Clewell et al. 2005, United States Department of Agriculture Natural Resources Conservation Service 2007, Parks Canada 2008, Rieger et al. 2014, McDonald et al. 2016). The phases—problem identification, defining goals and objectives, designing a restoration plan, implementation, and monitoring and evaluation—are intended to capture the general process undertaken in a broad range of restoration initiatives in order to provide a common, straightforward means of thinking about, and communicating different approaches to, restoration initiatives.

Each of Biggs et al.'s (2012) seven principles can inform the general phases of the ecological restoration process. Although each principle is understood to be relevant to all five phases of the restoration process, there are undoubtedly phases in which certain principles will play a more or less important role than will others. Context is a critical consideration in determining those differences. The large variation in the size and complexity of restoration initiatives suggests that the ways in which the principles are expressed in each phase will inevitably look different and as a result, the social and ecological outcomes will vary accordingly. With these considerations in mind, the conceptual framework is not prescriptive in nature, rather it communicates the potential for the seven generic principles for building resilience in SES to influence or inform the five general phases of ecological restoration process.

The conceptual framework also illustrates that a restoration process informed by the principles for building

Table 2. Conceptual framework illustrating the potential for Biggs et al.'s (2012) principles for building resilience in SES to inform the phases of the ecological restoration process and outcomes on the landscape.

			General Phases of Ecological Restoration Process					Restoration Outcomes	
			Problem identification	Defining goals and objectives	Designing a restoration plan	Implementation	Monitoring and evaluation	Ecological outcomes	Social outcomes
Principles for Building Resilience in SES	Key SES properties to be managed	Maintain diversity and redundancy							
		Manage connectivity							
		Manage slow variables and feedbacks							
	Key attributes of the governance system	Foster CAS thinking							
		Encourage learning and experimentation							
		Broaden participation							
		Promote polycentric governance systems							

resilience consequently manifests on the landscape as a series of social and ecological outcomes. This relationship between the restoration process and outcomes is essential as the aim of ecological restoration is ultimately to address degradation of ecological systems.

Applying the Framework to Assess Resilience Thinking and Practice: A Case Study

In order to empirically substantiate the conceptual framework, we used it to assess a case study of aquatic restoration. Specifically, "Trout Unlimited Canada's Stream Rehabilitation: From Form to Function Training Program" and three associated restoration projects. The training program was developed over several years in response to renewed interest in stream stewardship in Ontario, Canada (Imhof and FitzGibbon 2014) and in recognition that the majority of volunteer groups were lacking the necessary knowledge and training to develop and implement restoration projects. It consists of six workshops teaching trainees the theory, practice, and application of watershed and stream assessment and rehabilitation. This program was selected because it, unlike many other training programs, covers all of the general phases of the restoration process and purports to be based on the most current science. In addition to assessing the training program, three stream restoration projects (descriptions of each initiative are presented in sections A–C in Supplementary Material) informed by the training program were evaluated in terms of process and outcomes.

We operationalized the conceptual framework to enable both assessment (see framework in section D in Supplementary Material) and evaluation (see framework in section A in Supplementary Material). Consideration of outcomes were included when considering evaluation, with ecological outcomes gauged in relation to the three principles categorized as key SES properties to be managed and social outcomes considered in terms of the final four principles categorized as key attributes of the governance system. Although social outcomes pertain to all of the principles, ecological restoration was the primary focus of this study and evaluating all social outcomes, while important, was beyond the scope of this initial effort to test the conceptual framework. In order to determine what would constitute expressions of the principles, a set of criteria was established (Table 3). To assess the training program in relation to social-ecological resilience, semi-structured interviews were conducted with individuals involved in the development of the training program and document analysis was undertaken on program materials. In addition, websites, presentations, and personal communications with a key informant were drawn on for information regarding the history and evolution of the program.

Data collection with regard to the evaluation of restoration initiatives informed by the training program involved conducting semi-structured interviews with past trainees, obtaining secondary data where possible, and completing site visits for the collection of primary data in the absence of available secondary data (a detailed breakdown of data sources for the training program assessment is provided in section D in the Supplementary Materials and sections A–C for evaluation of each restoration initiative). Because the data collected that were related to restoration outcomes were unique to each initiative, the specific data collection procedures are described in detail, by initiative, in sections A–C in the Supplementary Material.

Deductive content analysis was performed on the training program manual and interview transcripts. Passages coded as evidence of a principle were subsequently coded for magnitude, differentiating coded data based on whether the principle was emphasized or simply mentioned. A similar process was followed for the analysis of interview transcripts relating to individual restoration initiatives' process and social outcomes. The treatment of biophysical data pertaining to ecological outcomes of the evaluated restoration initiatives is described in detail, by initiative, in sections A–C in the Supplementary Material. Ecological outcomes were evaluated with respect to whether or not they qualitatively reflect the criteria for the three principles considered key SES properties to be managed. Where ecological outcomes reflected criteria, the magnitude of that evidence was also evaluated. Magnitude here refers to the extent to which the ecological outcomes reflected the criteria at the time the data were collected as ecological outcomes of a restoration initiative can take many years to be fully realized. Magnitude was recorded either as ecological outcomes fully reflecting the criteria, or as appearing to be on a trajectory towards reflecting the criteria.

Results from the analysis of the training program are presented in Table 4. The assessment of the training program revealed that with one exception, all of the principles for building resilience in SES are expressed to some degree in what is taught about the five phases of restoration process. Examples of categories summarizing evidence of the principles from the assessment are reported in section D in the Supplementary Materials. Table 5 presents the results from the evaluation of the three restoration initiatives informed by the training program. Evidence of the principles was found across the phases of restoration process and social and ecological outcomes, although not in the same way across all three initiatives. Examples of the categories summarizing evidence of the principles from the evaluation of each initiative are provided in sections A–C in the Supplementary Materials.

Table 3. Criteria for judging the presence of principles for building resilience (Biggs et al. 2012) in the general phases of ecological restoration process.

Principle	Criteria	Examples
Maintain diversity and redundancy	*Diversity of system components* • Refers to the variety of elements in a system such as species and landscape patches, as well as the balance, or the proportion of each element, and how different those elements are from one another.	• A variety of native species that complement the surrounding landscape are included in riparian planting plans.
	Functional redundancy • Property of a system describing the presence of multiple components capable of contributing in equivalent ways to a particular function.	• Live stakes, live fascines, and seeding are all used for the purpose of bank stabilization and erosion control.
	Response diversity • The range of reactions or responses that components contributing to the same function have to change and disturbance.	• Project funding is reliant on more than one source.
Manage connectivity	*Appropriate structure of interactions between system components* • Pertains to links between system components both in terms of presence or absence of links as well as the distribution of links within a system.	• Landowners are educated about the importance of maintaining a riparian buffer to reduce fragmentation of the riparian corridor.
	Appropriate strength of interactions between system components • Refers to the intensity of the connections between system components.	• Regular contact with relevant stakeholders is maintained throughout the duration of the restoration project to provide updates and receive feedback.
Manage slow variables and feedbacks	*Feedbacks are managed appropriately* • Feedbacks that maintain desirable system configurations are strengthened and those that perpetuate undesirable configurations are disrupted.	• Bioengineering is used over hard-engineering and where possible, hard-engineered structures are replaced with more natural solutions.
	Key slow variables are monitored • Slow variables such as soil composition, legal systems, and values that determine the underlying structure of SES are monitored in terms of their proximity to thresholds.	• Changing attitudes are capitalized on by working with landowners to fence cattle out of creeks and/or restore a natural buffer.
Foster CAS thinking	*Holistic approaches are emphasized* • Refers to approaches that look at the system as a whole including interactions with scales above and below the focal scale.	• Problem identification involves looking beyond the reach scale to address causes, rather than symptoms, of problems.
	Unpredictability, uncertainty, and variability are accepted • Plans and decisions are made with the acknowledgement that change and surprise are inevitable and that solutions are context dependent. Restoration is adaptive to changing conditions.	• Goals and objectives focus on restoring ecosystem processes and functions rather than a specific historic or static state.
Encourage learning and experimentation	*Willingness to experiment* • Openness to actively manipulating certain SES processes and structures in novel ways to observe and evaluate outcomes.	• Different species are experimented with for stabilizing banks to see what is most effective in a particular situation.
	Knowledge sharing among actors and across scales • Knowledge shared at and beyond the focal scale.	• Restoration outcomes are shared through social media and traditional mediums to reach a wide audience across scales.
	Collaborative and long-term monitoring • Long-term collection of information about changes in SES carried out by several parties, not just specialist agencies.	• As part of a monitoring effort, anglers are encouraged to record and share information about fish species caught, as well as, any notable changes in the condition of the aquatic ecosystem.

Table 3, *continued*

Principle	Criteria	Examples
Broaden participation	*Relevant stakeholders are actively engaged* • Engagement of those who are actively interested in, directly impacted by, or are able to provide applicable local or scientific knowledge to a restoration initiative. Depending on the context, engagement can vary greatly from informing stakeholders of plans and activities to inclusion in all stages of the restoration process.	• Community members are invited to attend public meetings or open houses and are encouraged to ask questions about, and provide comment on, restoration plans and alternatives.
	Diverse types and sources of knowledge are brought together • Different types and sources of knowledge are welcomed and considered including local or experiential knowledge.	• Partnerships are formed between research institutions, conservation organizations, industry, and others to explore potential solutions to identified problems.
Promote polycentric governance systems	*Multiple governing authorities at different scales* • Deliberation and decision-making among multiple groups at different scales with various sources of authority, thereby allowing decision making to match the scale of the problem.	• A non-governmental organization, a Conservation Authority representative, and a landowner discuss and make decisions on the details of a small-scale restoration project on private property.
	Governance units have horizontal linkages • Refers to governance units' links with others at the same scale on common issues.	• Information and experiences are shared with community organizations in neighbouring watersheds.
	Governance units have vertical linkages • Refers to governance units' nesting within, and linkages with, scales above and below the focal scale.	• The organization leading a restoration initiative seeks advice from provincial and/or federal agencies as required.

Table 4. Results of the assessment of the *Stream Rehabilitation: From Form to Function Training Program* in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through the numbers 0 (absent), 1 (present), and 2 (emphasized in at least one instance).

		General Phases Of Ecological Restoration Process				
		Problem identification	Defining goals and objectives	Designing a restoration plan	Implementation	Monitoring and evaluation
Principles for Building Resilience in SES	Maintain diversity and redundancy	2	2	2	1	2
	Manage connectivity	2	2	2	1	2
	Manage slow variables and feedbacks	1	2	1	0	2
	Foster CAS thinking	2	2	2	1	2
	Encourage learning and experimentation	2	2	2	2	2
	Broaden participation	2	2	2	2	2
	Promote polycentric governance systems	1	1	2	2	1

Table 5. Overview of the evaluation of the three restoration initiatives in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through the numbers 0 (absent), 1 (present), and 2 (emphasized in at least one instance). NA = not assessed, NATA = not able to assess.

			General Phases of Ecological Restoration Process															**Restoration Outcomes**					
			Problem identification			Defining goals and objectives			Designing a restoration plan			Implementation			Monitoring and evaluation			Ecological outcomes			Social outcomes		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Principles for Building Resilience in SES	**Key SES properties to be managed**	Maintain diversity and redundancy	1	1	1	1	2	1	1	1	1	0	1	1	0	1	1	2	2	2	NA	NA	NA
		Manage connectivity	1	1	1	0	2	2	1	1	1	0	1	2	1	1	2	NATA	NATA	2	NA	NA	NA
		Manage slow variables and feedbacks	1	1	0	1	1	0	0	1	0	0	0	0	0	1	2	NATA	NATA	NATA	NA	NA	NA
	Key attributes of the governance system	Foster CAS thinking	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	NA	NA	NA	0	0	0
		Encourage learning and experimentation	1	1	0	1	0	2	1	1	1	1	1	2	1	1	2	NA	NA	NA	2	1	2
		Broaden participation	1	1	1	0	2	2	1	1	1	1	1	2	1	1	2	NA	NA	NA	2	2	1
		Promote polycentric governance systems	0	0	1	0	0	0	1	1	0	1	1	2	0	0	2	NA	NA	NA	2	0	1

Discussion

Ecological restoration scholarship has considered resilience in a variety of ecosystems for several years (see for example Allen et al. 2002, Suding et al. 2004, Palmer et al. 2005, Harris et al. 2006, Seavy et al. 2009). Recognition of the interdependencies between ecological and social systems is growing and scholars are increasingly discussing the need for, and potential benefits of, integrated approaches to restoration (Noss et al. 2006, Choi 2007, Zellmer and Gunderson 2008, Egan et al. 2011, Suding 2011, Perring et al. 2015, McDonald et al. 2016). The framework we developed in this study illustrates how social-ecological resilience and ecological restoration could conceptually be brought together. Employing the framework to assess and evaluate a case of aquatic ecosystem restoration presented the opportunity to critically assess how the framework stands up when practically applied.

The conceptual framework proved to be a useful guide for thinking about the assessment and evaluation of aquatic ecosystem restoration. Although restoration scholars have been discussing some of these resilience concepts in their work for several years, the value of the conceptual framework stems from the way each of the principles for building resilience is explicitly laid out in relation to the phases of restoration process and outcomes. In this way, the natural fit between ecological restoration and resilience principles is apparent and complements evolving perspectives in ecological restoration.

In applying the framework, we found utility in both the structure and flexibility it afforded when assessing the presence and magnitude of evidence of Biggs et al.'s (2012) principles in the process and outcomes of the case. We confirmed the applicability of the principles to an aquatic ecosystem restoration context in practice. This is a positive preliminary step and affirms the scholarly literature regarding the application of resilience concepts to ecological restoration (e.g., Palmer et al. 2005, Harris et al. 2006, Zellmer and Gunderson 2008, Suding 2011) in this particular context.

Our initial application of the conceptual framework also revealed challenges and limitations. The positive outcomes of the restoration initiatives in this preliminary study provide early signals, albeit an encouraging sign for restoration informed by social-ecological resilience. Ideally, the restoration initiatives will be evaluated again in the future to capture the full extent of social and ecological outcomes. The evaluation of outcomes using the conceptual framework is subject to some of the same challenges associated with more traditional approaches to evaluation of restoration outcomes (e.g., lag time, attribution issues, lack of detailed baseline data [Kondolf 1995, Choi 2004, Suding 2011, Wortley et al. 2013]). Some of these challenges, such as the delay in the realization of restoration outcomes, are simply a result of the nature of ecological restoration (Clewell and Aronson 2013) while others, a lack of detailed baseline data for instance, could be avoided with careful planning.

Moving from resilience thinking to resilience practice, while very important, comes with many challenges and is not an easy task (Cumming et al. 2005, Miller et al. 2010, Walker and Salt 2012, Plummer et al. 2014). While the conceptual framework was extremely helpful as a conceptual touchstone, making the principles operational was challenging. Specifically, it was difficult to determine how to measure Biggs et al.'s (2012) principles in assessing the training program and evaluating the three initiatives. For example, the data needed to evaluate for evidence of the presence of the principle "manage slow variables and feedbacks" in ecological outcomes were not available for any of the three initiatives. For this reason, they are marked as "NATA", not able to assess, in Table 5. This challenge is not unique to utilization of the framework and experience gained contributes to open questions in the literature about measurability, and use of proxies (Bennett et al. 2005, Cumming et al. 2005, Blythe 2015, Quinlan et al. 2015).

Conclusions

Maximizing the effectiveness of restoration efforts is essential. Emerging perspectives on ecological restoration call for consideration of complexity and linkages between social and ecological systems. Resilience thinking and practice offers a wealth of general insight, but relatively little specific guidance in relation to ecological restoration. In this paper we developed a conceptual framework which contributes to both ecological restoration and resilience scholarship by detailing how social-ecological resilience concepts can be incorporated into restoration. The framework was operationalized for, and proved useful in, the assessment of the training program and the evaluation of aquatic ecosystem restoration initiatives.

Critical consideration of the framework and initial employment in a specific type of ecological restoration reveals several avenues for future research efforts. Exploring the application of the conceptual framework in a range of restoration contexts (e.g., tallgrass prairie, meadow, forest) would provide valuable insights on the extent to which social-ecological resilience is reflected in current restoration practices more broadly. Where resilience is informing practices, an opportunity exists to determine if positive outcomes are being realized as a result. Comparisons and sharing of lessons learned across different types of restoration would thus be possible. Subsequent research may also build on this study by incorporating the conceptual framework from the start of a restoration initiative rather than introducing it first at the evaluation stage, expanding upon the evaluation of social outcomes, and considering large scale initiatives.

While an approach to restoration informed by social-ecological resilience offers considerable promise, it does not mean that success is guaranteed. There is much more to learn. Nevertheless, using the same approaches that have been proven ineffective is counterproductive and can be a waste of the often limited resources available. This new approach offers an opportunity to experiment and learn from that experimentation in order to advance the science of restoration ecology and its practice.

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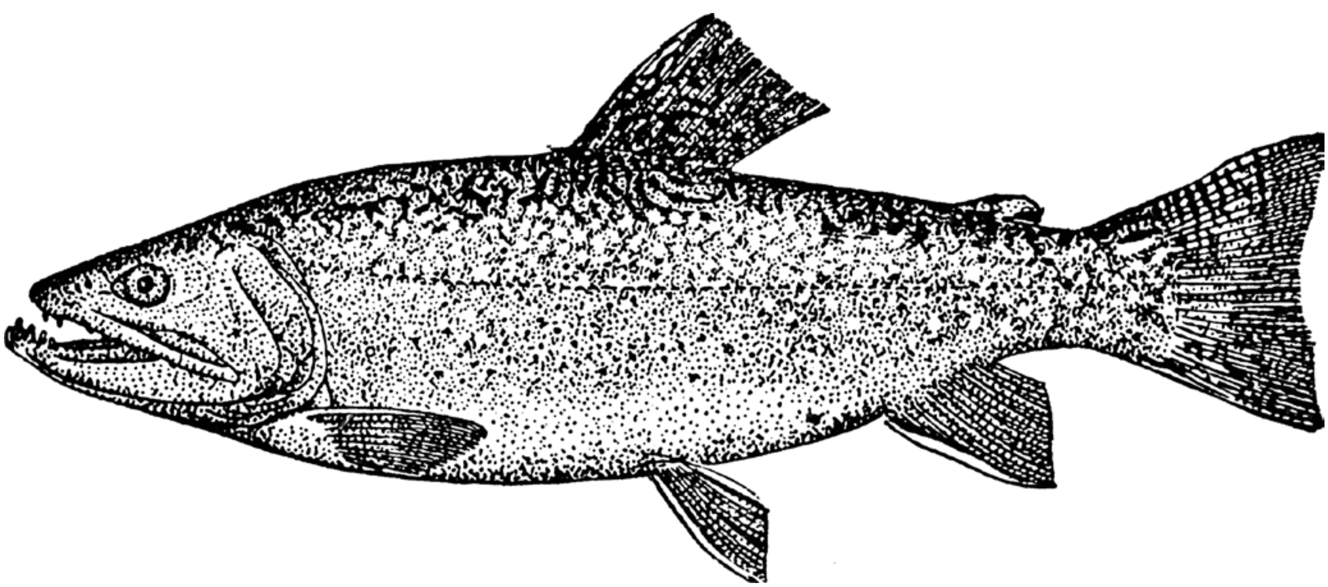

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