The Integration of Ecological Restoration and Science Education: Opportunities for Progress in Both Practices

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Abstract

Demanding ecological and educational challenges face ecologists and educators. In the United States, science students are falling behind their global peers and disengaging from science curriculum at a time in which ecosystem degradation and land use change are threatening ecosystem integrity. Broad theoretical knowledge exists in both disciplines to address these challenges; however, the implementation of theory impedes progress. The integration of ecological restoration and science education creates opportunities for progress in both practices. Ecological restoration would benefit from increased assessment and monitoring of restored ecosystems through school-based citizen science networks and increased community engagement and acceptance of restoration projects. Science education would benefit from increased authenticity and relevancy in the classroom, increased student engagement, and the development of scientific and environmental literacy.

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Introduction

Demanding and urgent ecological and educational challenges face ecologists and educators. The future strength of scientific education in the United States is uncertain as is the future integrity of global ecosystems. Broad theoretical knowledge exists in both disciplines to address these challenges; however, the implementation of theory remains a problem. The integration of ecological restoration and science education holds the potential for progress in both practices and addresses major problems and issues that impede implementation. Through integration, ecological restoration gains the ability to monitor restoration success through school-based citizen science networks and the enhancement of community engagement and acceptance of restoration projects. Science education gains authenticity and relevancy of science content, increased student engagement, and the development of scientific and environmental literacy.

Need for Science Education Improvement

The United States is facing a science education crisis. The Program for International Student Assessment (PISA) measures the performance of 15-year-old students in multiple countries every three years. In the 2006 assessment, scientific literacy was measured by a student's ability to identify scientific issues, explain phenomena scientifically, and use scientific evidence. Students in the United States scored lower than average in explaining phenomena scientifically and using scientific evidence (Table 1). Sixteen of the 29 developed countries in the study had higher average combined scores than the U.S., which also had greater percentages of students performing below or at the lowest proficiency level of scientific literacy than the overall average (Baldi et al., 2007). In 2009, student science literacy did rise to average; however, 12 countries had higher average scores (Table 2)(Fleischman, et al. 2010).

Table 1. 2006 PISA rankings for combined science literacy and science literacy subscales in The Organization for Economic Cooperation and Development (OECD) countries. Dark green represents an average higher than the U.S. average, white represents averages that are not measurably different, and light green represents averages lower than the U. S. averages (Baldi et al., 2007).

Combined science literacy scale		Science literacy subscales: Identifying scientific issues		Science literacy subscales: Explaining phenomena scientifically		Science literacy subscales: Using scientific evidence	
Jurisdiction	Score	Jurisdiction	Score	Jurisdiction	Score	Jurisdiction	Score
OECD average	500	OECD average	499	OECD average	500	OECD average	499
OECD jurisdictions		*OECD jurisdictions*		*OECD jurisdictions*		*OECD jurisdictions*	
Finland	563	Finland	555	Finland	566	Finland	567
Canada	534	New Zealand	536	Canada	531	Japan	544
Japan	531	Australia	535	Czech Republic	527	Canada	542
New Zealand	530	Netherlands	533	Japan	527	Korea, Republic of	538
Australia	527	Canada	532	New Zealand	522	New Zealand	537
Netherlands	525	Japan	522	Netherlands	522	Australia	531
Korea, Republic of	522	Korea, Republic of	519	Australia	520	Netherlands	526
Germany	516	Ireland	516	Germany	519	Switzerland	519
United Kingdom	515	Belgium	515	Hungary	518	Belgium	516
Czech Republic	513	Switzerland	515	United Kingdom	517	Germany	515
Switzerland	512	United Kingdom	514	Austria	516	United Kingdom	514
Austria	511	Germany	510	Korea, Republic of	512	France	511
Belgium	510	Austria	505	Sweden	510	Ireland	506
Ireland	508	Czech Republic	500	Switzerland	508	Austria	505
Hungary	504	France	499	Poland	506	Czech Republic	501
Sweden	503	Sweden	499	Ireland	505	Hungary	497
Poland	498	Iceland	494	Belgium	503	Sweden	496
Denmark	496	Denmark	493	Denmark	501	Poland	494
France	495	**United States**	**492**	Slovak Republic	501	Luxembourg	492
Iceland	491	Norway	489	Norway	495	Iceland	491
United States	**489**	Spain	489	Spain	490	Denmark	489
Slovak Republic	488	Portugal	486	Iceland	488	**United States**	**489**
Spain	488	Poland	483	**United States**	**486**	Spain	485
Norway	487	Luxembourg	483	Luxembourg	483	Slovak Republic	478
Luxembourg	486	Hungary	483	France	481	Norway	473
Italy	475	Slovak Republic	475	Italy	480	Portugal	472
Portugal	474	Italy	474	Greece	476	Italy	467
Greece	473	Greece	469	Portugal	469	Greece	465
Turkey	424	Turkey	427	Turkey	423	Turkey	417
Mexico	410	Mexico	421	Mexico	406	Mexico	402

Table 2. 2009 PISA rankings for science literacy in The Organization for Economic Cooperation and Development (OECD) countries. Red represents an average higher than the U.S. average, white represents averages that are not measurably different, and pink represents averages lower than the U. S. averages (Fleischman, et al. 2010).

Science literacy scale

Country	Score
OECD average	501
OECD countries	
Finland	554
Japan	539
Korea, Republic of	538
New Zealand	532
Canada	529
Estonia	528
Australia	527
Netherlands	522
Germany	520
Switzerland	517
United Kingdom	514
Slovenia	512
Poland	508
Ireland	508
Belgium	507
Hungary	503
United States	**502**
Czech Republic	500
Norway	500
Denmark	499
France	498
Iceland	496
Sweden	495
Austria	494
Portugal	493
Slovak Republic	490
Italy	489
Spain	488
Luxembourg	484
Greece	470
Israel	455
Turkey	454
Chile	447
Mexico	416

The decrease in science literacy and other science, technology, engineering, and mathematics (STEM) related skills and knowledge has the potential to affect society as a whole. Few students will go on to be producers of STEM knowledge, but all students will go on to be consumers of STEM knowledge. STEM literacy is essential for the advancement of science. All citizens will take part in important aspects of science such as adopting new technologies, funding research, and assessing the validity of new scientific applications. Despite these facts a 2008 study shows only 40% of students see learning about science as important for making informed decisions in their future (Farris-Berg and Tomorrow, 2008) .

STEM innovations have helped the US economy move forward and gain strength in the past; however, a 2012 study suggests that the United States global share of STEM industry is declining. Currently the number of undergraduate and graduate degrees in STEM fields is not keeping pace with the need for qualified STEM professionals and workers. K-12 and undergraduate education reforms are key to reversing this trend (Atkinson, 2012).

Compounding the problem of declining STEM literacy is the concomitant decline in environmental literacy. This decrease in understanding of environmental issues comes at a time when the complexity is increasing. Environmental literacy is essential to generating citizens capable of understanding complex environmental issues and actively participating in their resolutions (Cairns, 2000; Short, 2010).

Science education is failing to engage many students. This trend has been identified in the United States but is also a problem in schools worldwide. Survey data suggests that students perceive school science as irrelevant, repetitive, fragmented, and authoritarian in presentation.

Interestingly this disengagement in science is not related to achievement in science classes suggesting that achievement alone is not a measure of engagement with current scientific curriculum. This lack of engagement with science follows students into adulthood potentially decreasing public understanding of science (Turner and Peck, 2009) . Education as a whole is failing to engage many students. Disengagement is becoming an increasingly important idea in the discussion of national drop out rates even for gifted students (Landis and Reschly, 2013) . Data is emerging that indicates cognitive, behavioral, and affective disengagement are strong influences on students' decisions to leave school (Archambault, et al., 2009; Featherston III, 2010; Janosz, et al., 2008) .

Recently published curriculum frameworks are calling for innovation in science education. The National Academies of Science has developed the Framework for K-12 Science Education. This framework focuses on strengthening science education by ensuring that all students are educated in science to develop scientific literacy that will last a lifetime and provide the foundational knowledge for those that will have STEM careers in the future (National Research Council, 2012). The Partnership for 21st Century Skills created a framework designed to integrate all core academic subjects to teach the essential skills for success in the future. This framework explicitly calls for environmental literacy as an essential interdisciplinary theme. Cross-disciplinary learning objectives include focusing on knowledge and understanding of the environment, societal impact on the natural world, investigation and analysis of environmental issues, making conclusions about effective solutions, and taking individual and collective action addressing environmental challenges (Partnership for 21st Century Skills, 2009) .

Need for Ecological Restoration

The world is facing an ecological crisis. Ecosystems are changing faster in the second half of the twentieth century than any other time in recorded human history. The ecosystems most significantly altered include marine, freshwater, temperate broadleaf forests, temperate grasslands, Mediterranean forests, and tropical dry forests (Figure 1). Ecosystem processes such as carbon and water cycles have also been affected. The extinction of species and the invasion and introduction of new species are increasing the homogeneity of species distribution (Millennium Ecosystem Assessment, 2005).

Changes in land use have enabled humans to use an increasing share of the planet's resources, a share that is now estimated at one-third to one-half of global production (Foley et al., 2005). Growing demands on ecosystems are causing the degradation of ecosystem services and increasing the risk of nonlinear changes. (Millennium Ecosystem Assessment, 2005). Many ecosystems have been damaged to the point at which they can no longer recover quickly, adequately, or at all to meet the growing human demands (Clewell, et al., 2007) .

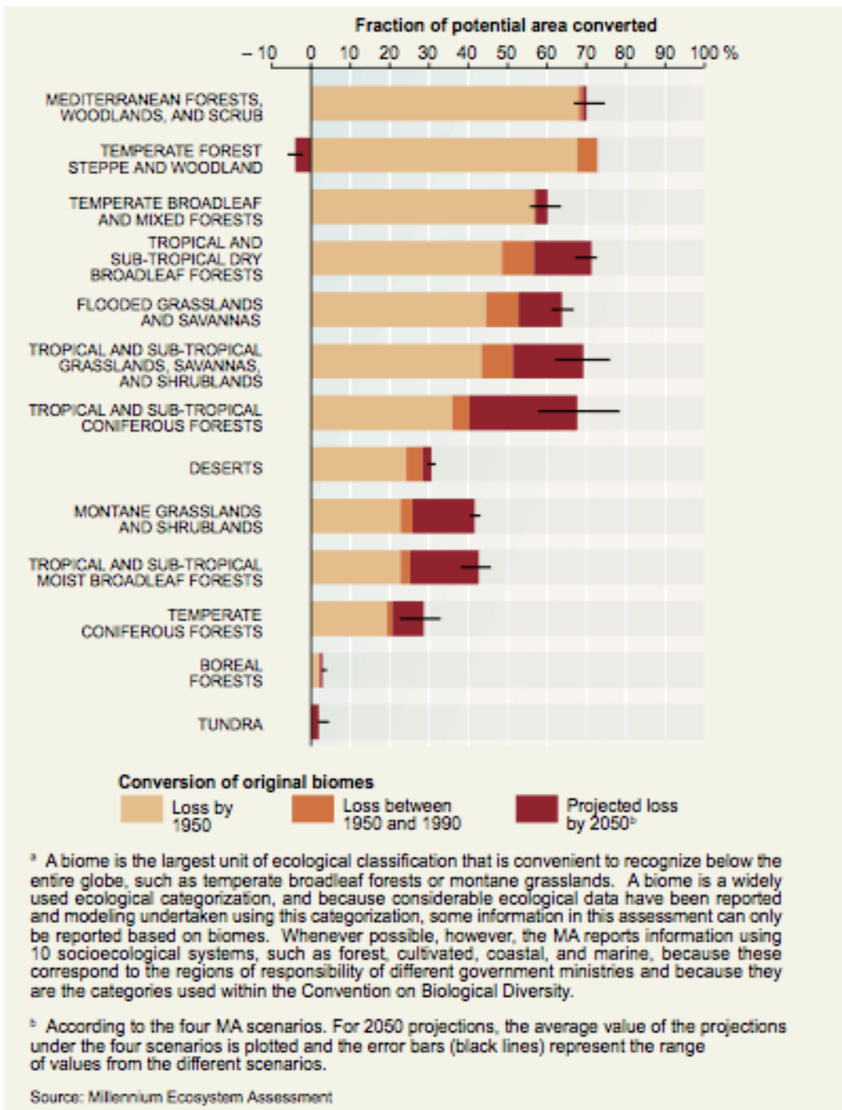

Figure 1. Conversion of potential area of global terrestrial biomes. Tan represents loss by 1950, orange between 1950 and 1990, and red represents the average projected loss by 2050 of the 4 MA scenarios (Millennium Ecosystem Assessment, 2005).

Direct and indirect drivers are causing the rapid pace of change in ecosystems and are consistent at best or intensifying at worst. Direct drivers include land use change (Figure 1), overexploitation, invasive alien species, pollution, and climate change. Indirect drivers of ecosystem change include global population increase, changes in economic activity, sociopolitical factors, cultural factors, and technological change (Millennium Ecosystem Assessment, 2005). These drivers often act synergistically to further transform ecosystems and increase the likelihood of nonlinear change (Suding, 2011).

Rapid land use change is a major threat to biodiversity (Dobson, et al., 1997; Foley et al., 2005). In many taxonomic groups, the population size or range of the majority of species is declining. The overall number of species on the planet is also decreasing. Currently 10-30% of mammal, bird, and amphibian species are threatened with extinction (Millennium Ecosystem Assessment, 2004). Models suggest that habitat loss actually creates an "extinction debt," (Dobson, 1997) or groups of species that will go extinct unless habitat is restored, thereby intensifying threats to biodiversity even after initial habitat loss.

The degradation of ecosystems affects the provision of ecosystem services on which human populations depend. In some cases, ecosystem services have been depleted to a degree in which the sustainability of the system as a whole is threatened (Comín, 2010). Many ecosystem services have been identified and are grouped into four categories: provisioning services, regulating services, cultural services, and supporting services. Provisioning services are products received from the ecosystem such as food, fiber, and fresh water. Regulating services are benefits from the regulation of ecosystem processes such as water regulation and climate regulation. Cultural services are nonmaterial benefits people obtain such as recreation, educational opportunities, and aesthetic experiences. Lastly supporting services are necessary for the production of all other ecosystem services indirectly or over a long period of time and include soil formation, photosynthesis, nutrient cycling, and water cycling (Millennium Ecosystem Assessment, 2004). Currently ecosystem services are provided without a market value. In an estimate of ecosystem service value through the year 2050, the value drops by $5,721 per unit area in the "business as usual" model compared to a scenario that includes restoration of degraded ecosystems (Comín, 2010) illustrating that current rates of degradation could have large economic impacts in the future if left unaddressed.

Ecological restoration demand is an inevitable consequence of increased environmental degradation and future environmental change (Suding, 2011), and the practice is now globally recognized as essential to long-term sustainability of a human dominated planet (Aronson and Alexander, 2013). The restoration of degraded ecosystems is increasingly becoming a primary focus of natural resource management in both terrestrial and aquatic environments (Millennium Ecosystem Assessment, 2005). Hobbs and Harris (2001) argue that it has to be an integral component of land management in today's world, and Ormerod (2003) suggests that restoration ecology is emerging as one of the most important disciplines in the whole of environmental science.

Environmental policy is also increasingly turning to ecological restoration (Suding, 2011). In the United States, The Clean Water Act of 1972 allows for the restoration or creation of wetlands to compensate for wetlands lost due to construction permits in order to maintain no net losses of wetlands. The Estuaries and Clean Waters Act of 2000 identifies its first two goals as "(1) to promote the restoration of estuary habitat and (2) to develop a national estuary habitat restoration strategy for creating and maintaining effective estuary habitat restoration partnerships among public agencies at all levels of government and to establish new partnerships between the public and private sectors."[1] The United States Department of Agriculture has committed to restoration in forest policy (Suding, 2011). The state of Louisiana is also turning to ecological restoration to protect its coastlines. Currently a $14 million dollar plan is in place to restore and protect 10,000 km^2 of coastal wetlands to reduce storm surges from hurricanes (Millennium Ecosystem Assessment, 2005).

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[1] Estuaries and Clean Waters Act of 2000,106 U.S.C. § S. 835. (1999).

International scientific organizations have also embraced restoration. At the 2010 meeting of the Convention on Biological Diversity in Nagoya, Japan, a new goal of restoring 15% of the degraded ecosystems worldwide by 2020 was set (Suding, 2011), and a roadmap to guide international efforts toward those goals was developed at their 2012 meeting by delegates from 168 countries (Aronson and Alexander, 2013). The Indonesian and Australian governments, and the United Nations Environment Programme all called for emphasis on restoration in the future (Suding, 2011).

Foundations in Educational Theory

The foundation for the development of solutions to current science education problems can be found in existing educational theory and is enhanced when used within the context of an ecological restoration project. A group of teaching philosophies, theories, and practices are emerging as essential to increasing scientific literacy, environmental literacy, and student engagement in the sciences. Constructivism, authentic instruction, inquiry, and project based learning are interrelated theories that can be used in all subject areas of education but are especially powerful in science education when used in combination with restoration ecology.

Constructivism

Constructivism has emerged as a dominant theory of learning (Nie, et al., 2013) from the foundational work of Piaget and Vygotsky. Constructivist theory is built around the assertion that knowledge must be constructed by the learner and not directly transferred from teacher to learner. Learning from this perspective is active and has both individual and social aspects. Knowledge construction is guided in the classroom by well-designed practical activities that give students latitude to challenge their own knowledge and reorganize their personal theories individually and while engaged with other student perspectives. The teacher is responsible for introducing new ideas while providing guidance and support for students to make sense of those ideas for themselves. This approach to science education aligns more closely with how actual scientific knowledge is constructed than traditional teaching methods (Driver et al., 1994).

Evidence suggests that constructivist approaches influence student achievement in the classroom. In a study of 9th grade students, constructivist instruction was a positive predictor of deep processing skills, self-efficacy, and task value (Nie et al., 2013). In a study of 8th grade students from 1,052 schools, students engaged in hands-on activities every day or once a week scored significantly higher on a standardized test of science achievement than students who spend less time engaged in hands-on activities (Stohr-Hunt, 1996).

Authentic Instruction

Authentic instruction is an educational theory and associated practices that focuses on making learning significant and meaningful through student use and development of skills of the discipline. Students are guided to construct meaning and produce knowledge, use inquiry to construct meaning, and focus their work on the production of discourse, products, and performances that have meaning and value beyond success at school. Five standards construct the framework that defines authentic curriculum: higher-order thinking, depth of knowledge, connectedness to the world, substantive conversation, and social support for student achievement (Newmann and Wehlage, 1993) .

Teaching practices associated with these standards are higher order questioning, metacognitive strategies, modeling, specific feedback, connections to prior learning, critical pedagogy, elaborated writing tasks, and assignments that connect to students' lives outside of school. Authentic instruction requires the mindset of the teacher to be focused on authentic learning rather than coverage of the material (Preus, 2012). Student achievement is affected by the use of authentic instruction. In a study of elementary and secondary schools, students receiving authentic instruction showed an average performance improvement from the 30^{th} to the 60^{th} percentile (Preus, 2012).

Relevancy is a strong theme throughout authentic instruction theory. Students need to connect what they are learning to their own world through skills used by professionals in the discipline. Authentic instruction benefits from interactions with scientists to help students see the relevancy of science and make meaning of scientific ideas. Connections between classrooms and scientists can provide conceptual support for students to make meaning of scientific phenomena or the nature of science itself (Peker and Dolan, 2012) . Scientific literacy is fostered through these interactions and other aspects of authentic instruction. Students that experience authentic instruction are more likely to identify science as useful and to integrate scientific ideas with other sources of meaning and experience in order to make decisions (Feinstein, 2011).

Inquiry

Inquiry-based instruction is integrated in both constructivism and authentic instruction. Inquiry methods align with the constructivist teaching philosophy and are core teaching strategies in authentic instruction. The term inquiry can refer to what scientists do, how students learn, and a pedagogical approach (Minner et al., 2010) . Inquiry is an active learning process in which students answer research questions by analyzing data. There are many different levels of inquiry, but all inquiry must start with a research questions and end with students analyzing data and supporting their conclusions with evidence. Inquiry based approaches exist in a continuum with four levels of increasing complexity and student involvement: confirmation inquiry, structured inquiry, guided inquiry, and open inquiry (Table 1). Conformation inquiry provides the most guidance for students. The research question and methods are provided, and the solution has already been discussed in class. Open inquiry provides the least guidance for students. The students construct the research question, methods, and solution, designing and conducting the investigation at every step. Students progress from confirmation inquiry to open inquiry as their skills develop (Bell et al., 2005).

Table 3. The four level model of inquiry (Gengarelly and Abrams, 2008 adapted from Bell et al., 2005).

Level of inquiry	Question	Methods	Solution
1 (confirmation)	X	X	X
2 (structured)	X	X	
3 (guided)	X		
4 (open)			

The X marks what is provided by the teacher

Inquiry based instruction positively affects student achievement. A synthesis of 138 studies of inquiry use in the classroom illustrated that a majority of students showed positive impacts with some level of inquiry in the classroom. In the studies that compared inquiry based methods to more traditional methods, students exposed to higher amounts of inquiry did significantly better than those with lower amounts of inquiry. The trends suggest that instruction that emphasizes students actively thinking about and participating in the investigation process increases science conceptual learning (Minner et al., 2010). In a study that compared hands-on and inquiry-based learning to traditional methods relying on textbook reading in high school biology, inquiry-based approaches resulted in more authentic learning experiences. The amount of time students spent reading biology textbooks did not affect learning outcomes (Wyss et al., 2013) .

Project Based Learning

Project based learning (PBL) also aligns with the constructivist philosophy of learning and is a core teaching strategy in authentic instruction. PBL is closely related to inquiry-based instruction in that it also focuses on the extensive use of student-directed inquiry. Project-based learning integrates four main features: (1) students are engaged in the investigation of a real-world question or problem that drives instruction and organizes concepts or principles to be learned, (2) students develop a series of products that address the question or problem, (3) students are collaborating with teachers and other members of the community about the problem, and (4) student use of cognitive tools is promoted (Schneider et al., 2002) .

Project based learning has also been shown to increase student achievement. A sample of 10th and 11th graders enrolled in a PBL program outscored a comparative group of students that did not receive PBL by 44% on a nationally standardized science test (Schneider et al., 2002). Science achievement in minority students also increased with PBL addressing a group of students underrepresented in post-secondary STEM education and careers (Kanter and Konstantopoulos, 2010) .

Conceptual Framework of Ecological Restoration

Ecological restoration is an ideal platform for innovation in science education. In the broadest sense, ecological restoration is an interventionist approach to reaching specific ecological goals (Clewell et al., 2007; Hobbs and Cramer, 2008; Hobbs and Harris, 2001) . Similarly restoration has been described as degradation in reverse (Clewell, et al., 2007). The core of the framework consists of goals focused on ecological fidelity; however, the framework is expanding (Figure 2). Higgs (1997) suggests that the framework should expand to include both economic and social aspects of restoration projects.

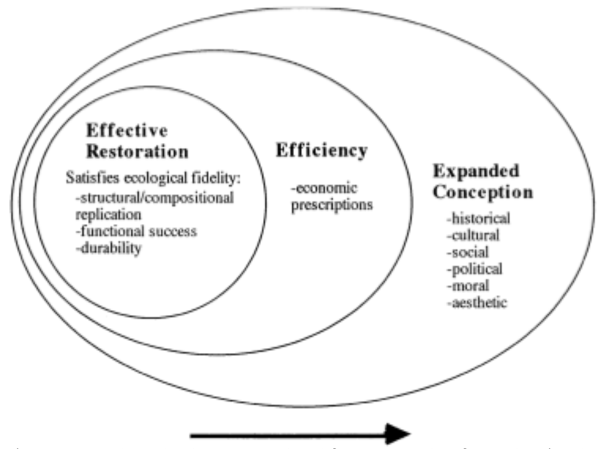

Figure 2. Extended conceptual framework of ecological restoration (Higgs, 1997).

Ecological restoration is inclusive. Practices exist on a continuum incorporating many forms of restoration with varying goals and interventions (Figure 3). The continuum ranges from returning a degraded ecosystem to an exact replication of a predetermined ecosystem, to restoration that simply returns a degraded ecosystem to some kind of functioning ecosystem (Hobbs and Cramer, 2008; Hobbs and Norton, 1996). Restoration projects include many different spatial scales, environmental stressors, and intervention strategies (Figure 4).

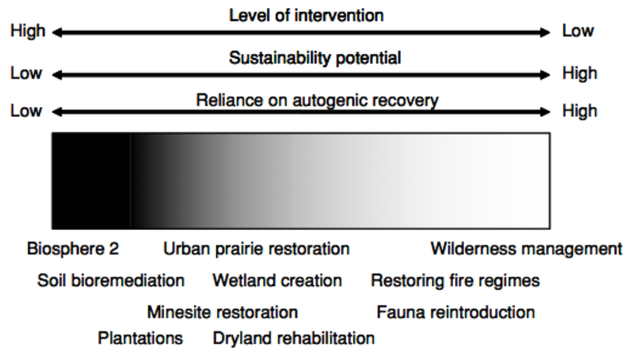

Figure 3. Possible interventions and goals on the continuum of restoration practices. Low levels of intervention rely on high autogenic recovery in the ecosystem (Hobbs and Cramer 2008).

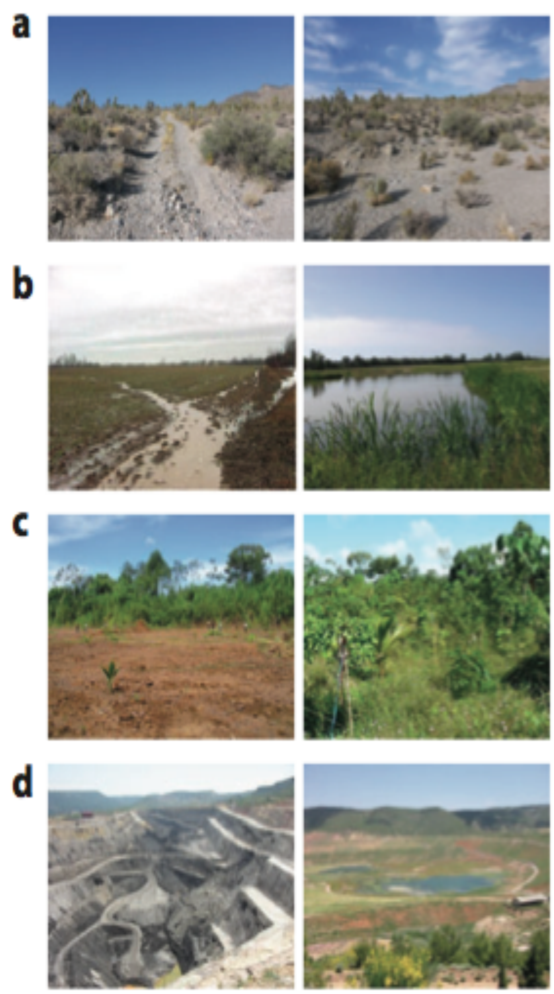

Figure 4. Before and after pictures of restoration projects. (a) Road decommissioning at Desert National Wildlife Refuge, Las Vegas, NV; (b) Fort Erie wetland restoration, Ontario, Canada; (c) Proyecto Naturaleza y Cominidad, Costa Rica; and (d) coal mine restoration, Spain (Suding, 2011).

Regardless of a restoration project's place on the continuum, restoration can never replace the conservation of intact ecosystems (Higgs, 2003; Hobbs and Norton, 1996; Hobbs and Harris, 2001) . Ecological restoration should be part of the broader context of sustainable land use, not a replacement (Higgs, 2003). Conserved, undegraded ecosystems are a necessary part of setting goals for healthy ecosystem functioning in a restored ecosystem (Hobbs and Harris, 2001) , making restoration dependent on the continuation of conservation.

Ecological restoration as a discipline developed through its early years, and the definition of the term ecological restoration still continues to develop. Its interpretation has been and still is the subject of debate. The Society for Ecological Restoration (SER) International developed the *Primer on Ecological Restoration*. This foundational document in the practice of ecological restoration defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (2004). Ecological restoration is an intentional activity that initiates the recovery of an ecosystem using a range of interventions, to return degraded ecosystems to their historical trajectory with respect to ecosystem health, integrity, stability, and sustainability. Restoration is an indefinitely long-term commitment of land and resources (SER International, 2004). The current definition focuses more on the recovery of ecosystem function and processes and less on the reconstruction of past species assemblages (Choi et al., 2008).

The words and phrases used in this definition need clarification in order to accurately describe ecological restoration. An ecosystem, in the context of restoration, consists of biota, the physical environment surrounding those species, and the interactions among them. This unit can be recognized as a spatial unit of any size ranging from a small site with only a few individual species to a large site at the landscape scale that shows structural and species composition homogeneity, to an even larger biome-based ecosystem. However, regardless of ecosystem size, restoration is always approached from the landscape scale to promote interactions with adjacent ecosystems (SER International, 2004).

Assisted recovery can have many meanings. In the practice of ecological restoration, it is an intentional intervention, not the recovery of the ecosystem solely through successional processes. The continuum of interventions, however, is very broad. Assisted recovery can be initiated by interventions as simple as removing a stressor such as grazing or as complex as altering hydrologic flows, changing soil properties, or planting native species. The degree of assisted recovery is dictated by conditions in the ecosystem (Higgs, 2003).

The meanings of the terms degraded, damaged and destroyed are similar and interconnected. All three terms refer to some degree of divergence from the normal healthy state of an intact ecosystem. Degradation is a subtle or gradual change that reduces ecosystem integrity and health, and damage refers to acute and obvious changes. The ecosystem is destroyed if degradation or damage is so extensive that all macroscopic life is removed and the physical environment is damaged (SER International, 2004).

One of the most difficult and debated terms to clarify in the definition of ecological restoration is the historical trajectory or historical range of variability of an ecosystem. The ecological trajectory is the developmental pathway of an ecosystem through time, starting with the unrestored ecosystem and progressing toward the desired state describing all abiotic and biotic attributes of the ecosystem. This trajectory is not specific. It incorporates a broad yet confined range of potential ecological expressions through time (SER International, 2004). The specific definition of this trajectory is complex because ecosystems are undergoing constant change influenced by both predictable and stochastic processes making the precise trajectory of an ecosystem impossible to predict. Restoration practitioners must construct the historical range of variability based on reference conditions to help define restoration goals (Higgs, 2003).

Foundations in Ecological Theory

Ecological restoration exists as part of a hierarchy that includes restoration ecology and ecological theory (Figure 5). Restoration ecology focuses on conceptual restoration, and ecological restoration focuses on practical restoration (Burke and Mitchell, 2007) as a discipline of applied science (Choi et al., 2008). Both restoration ecology and ecological restoration are informed by ecological theory.

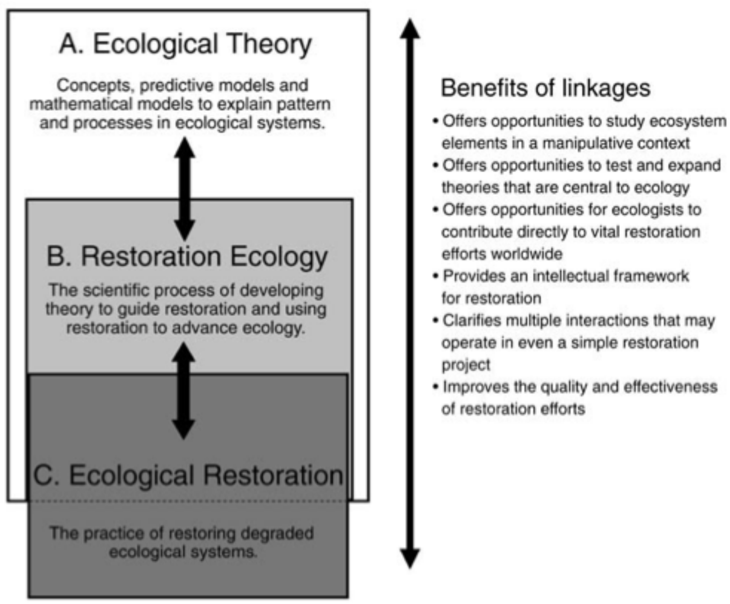

Figure 5. The hierarchy and connections between ecological theory, restoration ecology, and ecological restoration. Some restoration projects progress without guidance from ecological theory (bottom of dark box) (Falk et al., 2006).

The connections between ecological theory and restoration are mutually beneficial. A strong foundation in ecological theory benefits restoration ecology and the practice of ecological restoration.

Conversely, ecological theory benefits from the opportunities ecological restoration projects provide for experimentation and data collection. Restoration projects also provide ecologists with an avenue to contribute directly to restoration efforts (Burke and Mitchell, 2007; Cabin, 2007; Falk et al., 2006) .

The connection between ecological theory and restoration is challenging to sustain. Many restoration projects are planned and implemented without strong knowledge or application of ecological theory (Figure 5). The lack of connection between scientists and restoration practitioners may be due to a lack of involvement of scientists in the restoration efforts (Arlettaz et al., 2010) or the lack of professional support to focus research approaches to solving practical applied problems (Cabin, 2007).

Every aspect of ecological restoration can be informed by existing ecological theory. Useful theory ranges in spatial and temporal scale and includes disciplines such as population genetics, ecophysiology, demography, community and evolutionary ecology, food webs, biodiversity, ecosystem functioning, paleoecology, climate change, and macroecology (Falk et al., 2006). A complete discussion of the foundations of ecological theory in restoration ecology is beyond the scope of this paper; however, a brief look at some of the predominant areas of ecological theory such as regional processes, heterogeneity, and the dynamic nature of ecosystems, will illustrate the connections between ecological theory and restoration practices.

Regional Processes

Regional processes operating at large spatial scales influence restoration progress. The regional species pool affects species diversity and assemblage, and dispersal influences species establishment at the restoration site. The colonization sequence influences community development in the restoration site. Environmental conditions are also important to restoration progress. Abiotic filters, such as light, chemical characteristics and hydrologic characteristics, can affect the ability of species to establish successfully according to the species tolerance and productivity and affect restoration progress to a larger degree in harsher conditions. Natural disturbances, such as fire and flooding can be a strong influence in certain ecosystems. Ecosystems include a community of organisms making biotic interactions important to restoration progress. Competition theory predicts interactions among species. Trophic interaction theory can help predict the influence of top-down or bottom-up control in the restored ecosystem. Mutualistic interactions can also influence restoration progress. These positive interactions vary in mechanism and include interactions such as seed dispersal, substrate stabilization, and micorrhizal fungi associations with plant roots to facilitate nutrient acquisition (Falk et al., 2006).

Heterogeneity

Ecosystem heterogeneity theory is important to consider in restoration progress. Increased topographic heterogeneity causes variation in the physical environment influencing chemical and biological processes at a small scale. The variations can be manipulated during the restoration process to support the structure of biotic communities (Falk et al., 2006) and have been used in restoration practice to influence community structure. Heterogeneity influences ecosystems more heavily if there are more than one dominating species across a range of resource availability (Baer et al., 2005) .

Dynamic Nature of Ecosystems

Theory describing the dynamic nature of ecosystems is increasingly recognized as an influence on restoration progress. Classic successional theory rooted in the work of Clements and Odum describe successional processes as steady directional change in species composition to a single equilibrium point (Falk et al., 2006). Research has shown that succession may not be deterministic but stochastic making change in species composition generally directional, reticulate, regressive, or even cyclic (Choi et al., 2008). Communities can also shift between multiple stable states influenced by shifts in ecosystem variables or drivers (Beisneret et al., 2003) . Shifts between stable states can create thresholds in ecosystem variables and drivers that need to be addressed in restoration (Hobbs and Harris, 2001) . These developing areas of ecological theory have implications in guiding the restoration of degraded ecosystems that do not respond to successional-based approaches (Suding et al., 2004). Broad areas of ecological theory can be used to construct predictive models which can be valuable tools in restoration planning, progress, and success (Choi et al., 2008).

Elements of Restoration

Restoration is founded in ecological theory, but the practice itself varies greatly. Ecological restoration is a complex process involving the manipulation of many variables and progression through many steps. SER International describes 51 guidelines to restore degraded ecosystems in *Guidelines for Developing and Managing Ecological Restoration Projects* (2005). There are common elements to every restoration project, however, which can be consolidated into three interconnected phases: intent, process, and product (Higgs, 2003).

Intent

Clewell and Aronson (2006) suggest that motivations for restoration fit into four broad rationales: technocratic, biotic, heuristic, idealistic, and pragmatic. The technocratic rationale focuses on the restoration of services of societal value and is often performed by government agencies or large corporations. The biotic rationale focuses on the preservation of biodiversity or a single threatened species. The focus of the heuristic rationale is scientific progress that uses restoration as a proving ground for ecological theory or for demonstrations of ecological science. The idealistic rationale focuses on the attachment people have to place and is embodied by local populations. Finally, the pragmatic rationale focuses on the restoration of natural capital and the reversal of ecosystem change due to anthropogenic drivers. The melding of the technocratic and idealistic may be the most beneficial for successful restoration projects (Clewell and Aronson, 2006) .

The motivations behind the decision to restore degraded ecosystems vary, as do the approaches to restoration. Approaches differ because of the variables surrounding the restoration project and intent of the restoration practitioners. A simple approach to restoration is to guide the recovery of a degraded ecosystem. This approach is generally based in successional processes that eventually change the ecosystem back to a previous species composition. These restoration projects can result in a quick recovery if mechanisms still exist in the ecosystem to progress through predicted successional changes such as seed banks and abiotic conditions. If mechanisms are no longer in place, however, species composition may not revert to previous species compositions. Even if goals that align with previous conditions are not met, these approaches are often more effective than no action at all (Suding, 2011).

Compensation for habitat loss is another approach to restoration. This approach is often used to fulfill environmental policy mandates while facilitating development (Suding, 2011) such as the Clean Water Act in the United States. Uncertainty in restoration success makes this approach open to scrutiny. For example, in the Cuyahoga River Watershed in northeastern Ohio, 67% of restored and created wetlands did not meet permit requirements issued under the Clean Water Act (Kettlewell et al., 2008), and in Orange County, CA 45% were not successful (Sudol and Ambrose, 2002).

The most inclusive approach to restoration focuses on the restoration of biodiversity in the ecosystem. Biodiversity restoration can be a mechanism to increase or restore ecosystem services. This approach often incorporates a valuation system to assign monetary value to ecosystem services, and influences ecosystem priority decisions (Suding, 2011). A meta-analysis of ecological restoration projects in diverse ecosystem types illustrated that restoration projects increased biodiversity by 44% and ecosystem services by 25% even though values were still lower than the reference ecosystems (Rey Benayas et al., 2009). Increasing biodiversity can also be a method to increase the resilience of an ecosystem. Resilience is an important goal in restoration because it ensures the projects sustainability in a future with certain global environmental change. This approach is hard to assess because resilience is very challenging to quantify and measure (Suding, 2011).

The most important aspect of the intent of the restoration process is the identification of restoration goals (Comín, 2010; Ehrenfeld, 2000; Hobbs and Harris, 2001; SER International, 2004). All restoration projects share some basic goals focusing on recovering ecosystem integrity, health, and sustainability (SER International, 2005); however, many goals are site specific and tailored to what is realistic in that particular degraded ecosystem and restoration project (Ehrenfeld, 2000; Hobbs and Harris, 2001).

Restoration goals are effective when clear and specific. This is contradicted by the fact that ecosystems are dynamic, vary at many spatial and temporal scales, and are changing faster than ever due to anthropogenic pressures. To resolve this contradiction, goals need to be more open-ended yet as clear and specific as possible. Appropriate goals describe a trajectory of ecosystem change rather than static, historical, compositional or structural characteristics (Hobbs, 2007; Hobbs and Norton, 1996; Hobbs and Harris, 2001; Hughes et al., 2012) . Goal setting may also need to be expanded to include sets of conditions under which different goals will be appropriate (Ehrenfeld, 2000). Open-ended goals are often the best option in inherently dynamic systems such as remote or large areas, ecosystems in which limiting factors will change in future climates, ecosystems in which previous conditions can not be replicated, ecosystems strongly reliant of processes outside of the restoration area (Hughes et al., 2012).

Selection of reference information is an integral part of restoration goal setting and distinguishes it from other environmental interventions such as reclamation, regeneration, or reintroductions (Clewell et al., 2007). The most common forms of data used to construct restoration goals are historical data from the site and contemporary data from a reference ecosystem that is similar to the restoration site. Interpretation of this data, however, is a very challenging task. Ecosystems are complex and vary on many spatial and temporal scales, which complicate the interpretation of data. Historical data can be influenced by unknown factors driving trends in data, and reference ecosystem data is only useful if the site is a close approximation to the restoration site in relevant ecological characteristics (White and Walker, 1997) .

The core of restoration goals lies in ecosystem structure and function, but cultural and societal goals are also important to the success of a restoration project. Cultural goals provide the foundation for public understanding and appreciation for the restored ecosystem (SER International, 2005). If feasible cultural goals are not included, the restoration project can fail due to public misunderstanding of the science and technology behind the work (Cairns, 2000).

Process

Variation in the restoration site itself has important implications for the restoration process. The size of the degraded ecosystem to be restored and its spatial context within the landscape greatly influence restoration practice. The size of the ecosystem affects restoration decisions because ecological processes and functions happen at varying spatial and temporal scales that extend beyond project boundaries (Falk et al., 2006). For this reason a landscape-scale perspective is beneficial to meet restoration goals and ensure the integration of the restored ecosystem into the existing surrounding ecosystems (Falk et al., 2006; Hobbs and Norton, 1996) . Restoration sites must also be large enough to support self-sustaining populations (Brudvig, 2011). The initial state of the restoration site can affect the restoration process. Ecological restoration does have limits and some ecosystems are too degraded to be restored with available resources or current technology (Hobbs and Cramer, 2008) . The history of the restoration must also be taken into consideration when planning a restoration project. Some historical elements of the ecosystem can be manipulated during restoration, such as species arrival order and initial species composition. Other historical elements can influence restoration progress, but are not easily manipulated during restoration. These elements include the type or intensity of past disturbance that result in land-use legacies such as destruction of seed banks or soil profiles (Brudvig, 2011).

A wide array of intervention strategies exists to meet restoration goals. Intervention strategies exist on a continuum from a "do nothing" approach to a combination of abiotic and biotic interventions coupled with adaptive management (Hobbs and Cramer, 2008) . An essential part of any restoration intervention is the elimination of the stressor on the ecosystem. Stressors are any recurring factors that discourage the establishment of what are normally competitive species and include fires, anoxia, drought, salinity shocks, unstable substrates and nutrient pollution (SER International, 2004). Stressors can impact different parts of ecosystem structure and function changing the intensity of the impact of the stressor on the ecosystem (Figure 6). High intensity stressors often act on resource supplies while low intensity stressors act on other parts of the ecosystem. Stressors with low intensity impact are more easily reversed through removal of the stressor alone.

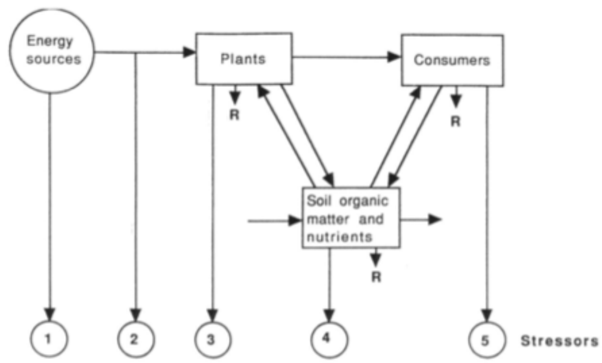

Figure 6. Simplified model of an ecosystem including inputs, major components, and flows. Circles 1-5 represent potential stressors. The impacts of stressors 1 and 2 potentially have the highest intensity because they act on resource supplies (Hobbs and Norton, 1996) depending on control regime in the ecosystem.

The removal of stressors is often not enough to meet restoration goals necessitating further abiotic intervention, biotic intervention, or a combination of strategies. Abiotic interventions are implemented to change the physical or chemical environment to facilitate ecosystem restoration. These interventions include the reinstatement of river structures such as meanders and riffle-pool sequences, changing topography to retain water, reinstating or improving soil structure or chemistry, and altering fire regimes (Hobbs and Cramer, 2008) .

Biotic interventions are implemented to reintroduce a species or group of species determined as desirable in the goals of the restoration project. Plant community structure is often the focus of biotic interventions but can include the addition or reintroduction of species, control of herbivory or grazing, structural alteration of vegetation to alter fire patterns, and the removal of nonnative species. Methods of biotic intervention vary depending on initial site conditions and restoration goals. Restoration sites devoid of any initial plant species will depend heavily on plantings and successional patterns; however, sites with some initial plant communities may only need interventions that enhance existing seed dispersal. In other cases, control of grazing or the reintroduction of fauna can facilitate the emergence of desired plant communities or other restoration goals (Hobbs and Cramer, 2008) .

Combinations of abiotic and biotic interventions may be necessary to reach restoration goals in complex restoration projects. Abiotic interventions are often followed by biotic interventions, such as creating a structure to retain water and then planting desired wetland species to restore a wetland. Broad scale interventions at the landscape scale that utilize combinations of interventions with the addition of continued management may be needed to reach restoration goals focused on increasing connectivity or restoring regional landscape structures and functions (Hobbs and Cramer, 2008) .

Product

The final phase in a restoration project is the assessment and ongoing monitoring of the restored ecosystem. Attributes that are assessed are specific to individual ecosystems and restoration projects; however, SER International (2005) identified nine overarching attributes of restored ecosystems. These attributes can be organized into four categories: species composition, ecosystem function, ecosystem stability, and landscape context (Shakelford et al. 2013). Species composition attributes focus on the presence of characteristic species assemblages and native species in the restored ecosystem. Ecosystem function attributes refer to the presence of necessary functional groups, aspects of the physical environment to support reproducing populations, and normal functioning levels for the equivalent stage of ecosystem development. Landscape context attributes focus on the incorporation of the restored ecosystem with the larger landscape including flows, exchanges, and threats. Finally, ecosystem stability attributes focus on ecosystem resilience to normal stress events and the ability of the ecosystem to self-sustain (SER International, 2004).

Assessment and monitoring of restored ecosystem attributes are essential to the progress of ecological restoration as a practice (Hobbs and Norton, 1996; Hobbs and Harris, 2001; Suding, 2011) , yet comprehensive assessments of successes and failures are rare (Suding, 2011). In an analysis of 468 articles published in *Restoration Ecology,* only 68% evaluated restoration success and of those that did evaluate success, the majority evaluated only one group of organisms. No studies evaluated all of the attributes of a restored ecosystem defined by SER International. Many ecosystem attributes require long-term study, however, monitoring rarely lasts longer than five years (Ruiz-Jaen and Aide, 2005) . SER International (2005) suggests assessing whether performance standards are met and assessing the attainment of project objectives. An ecological evaluation of the newly restored ecosystem should be conducted if clear goals were not set. Evaluation data is also needed to indicate if adaptive management is required to reach project goals.

Assessment of the success of restoration has developed as the practice of ecological restoration has developed. Biological potential inventory was likely the earliest form of ecosystem assessment, which later increased in complexity by incorporating food web and symbiotic relationship assessment (Hobbs and Harris, 2001) . More than one variable in three general categories of ecosystem attributes (diversity, vegetation structure, and ecological processes) should be measured and compared with more than one reference site to incorporate the inherent variance in ecosystems (Ruiz-Jaen and Aide, 2005) . Ecosystem indicators that have been used to assess the success of restoration include species richness, Shannon diversity, and multivariate analyses; however, these indicators do not assess community integrity. Recently the Community Structure Integrity Index and Higher Abundance Index have been suggested as a better way to assess the success of restoration and the resilience of plant communities (Jaunatre et al., 2013).

The assessment of restored ecosystems has also been developing more rigorous statistical evaluation. The challenge lies in comparing the restored site to something that cannot be observed, what the site would be had it not been restored. Ecosystem assessment is also extremely challenging due to the immense number of variables affecting all reference and restoration sites. Finding a control site for statistical analysis is difficult; accounting for the innate variation in space and time in both the reference and restored ecosystem is complex; and separating local and regional effects heavily influence the analysis and interpretation of data. A promising assessment design is the Before-After-Control-Impact (BACI) design. This design incorporates spatial and temporal variation by sampling one or more reference sites (control site) and the restored site (impact site), both before and after restoration (Falk et al., 2006).

Integration of Ecological Restoration and Science Education

Ecologists are struggling with the threats of widespread ecosystem degradation, and science educators are struggling with disengaged students and decreasing science and environmental literacy. Broad theoretical knowledge exists in both disciplines; however, the implementation of theory continues to impede progress. The integration of ecological restoration and science education holds the potential for progress in both practices. The benefits of integration are mutualistic, but the gains in each practice differ.

Opportunities for Ecological Restoration Progress

The success of individual ecological restoration projects and the progression of the discipline rely on quality assessment, evaluation, and monitoring of ecosystems before and after the restoration process (Hobbs and Norton, 1996; Palmer et al., 2005; Suding, 2011) . Despite the clear need for assessment, comprehensive evaluation of the successes and failures of restoration are rare (Suding, 2011). A synthesis study of river restoration found that less than half of all projects set measurable goals and used quantitative measurements to evaluate project success (Palmer et al., 2005).

The assessment of restored ecosystems, especially long term monitoring, can be time intensive and exceed the budgets of most restoration projects (SER International, 2004). Restoration practitioners can reach out to schools and the community to create networks to facilitate standardized monitoring and assessment. A school-based monitoring network could potentially extend the length of the monitoring period and increase the frequency of measurements to best fit restoration goals. Citizen science projects are currently engaging non-professional scientists in ecological research expanding the scope of what ecologists can accomplish (Dickinson et al., 2012). Ecological restoration projects partnering with schools near the restoration site could be a source of consistent citizen science volunteers to supplement data collection needs year after year.

The most significant opportunity for progress arising from the integration of restoration and science education is the enhancement of community engagement and acceptance. The success of all ecological restoration projects relies heavily on public understanding and support of the project (Cairns, 2000; Choi et al., 2008; Clewell and Aronson, 2006; Hobbs and Cramer, 2008; Miller and Hobbs, 2007; Palmer et al., 2004). Public acceptance and appreciation are essential for acquiring funding, bringing stakeholders in to participate in planning and implementation of the project, and is even more important for the long-term protection and management of the restored ecosystem (SER International, 2004). Schools are an efficient and meaningful way for restoration practitioners to connect to the community to garner support for restoration and educate the community about the benefits of the restored ecosystem.

The field of ecology is undergoing a paradigm shift. The conceptual framework is expanding to include humans in ecosystems transitioning from a reductionist view to a systems view of the biosphere bringing ecology to the nexus of humans, nature, science, and society. This shift is integrating science into society (Bradshaw and Bekoff, 2001;

Palmer et al., 2004) emphasizing the importance of communication between scientists and non-scientific audiences. Communicating science and addressing societal concerns about environmental issues is becoming an increasingly important part of professional ecologists careers (Pace et al., 2010).

The integration of restoration ecology and science education would provide a direct conduit for ecologists to engage with non-scientific audiences. Schools have strong preexisting networks that restoration ecologists can tap into making outreach more efficient without sacrificing quality. Teachers and administration would support restoration ecologists as they learn to communicate with and engage non-scientific audiences. Effective communication will increase the relevancy of their research and restoration projects in the local community.

The literature clearly indicates the need for public acceptance and engagement in the restoration process; however, a substantial research gap examining the effects of outreach and education on the success of ecological restoration projects still exists. There are few examples of projects with comprehensive and long term monitoring data in general, and there are even fewer specifically measuring the effect of outreach and education on the success of restoration. Nearly all of the environmental education and outreach programs are evaluated by educational objectives alone with no focus on the actual impacts on the ecosystem. Of the few studies that do focus on both outcomes, little support or evidence of the relationship between education and outreach and their impact on the ecosystem is described (Short, 2010).

Opportunities for Science Education Progress

Ecological restoration projects will infuse science education with authenticity and relevancy for students. These projects would be tangible representations of the importance and applicability of the scientific principles learned and experienced in the classroom. Partnerships with restoration ecologists and practitioners would empower students to refine and utilize inquiry skills thus strengthening and deepening their understanding of the nature of science.

This partnership is equally powerful for teachers. A strong indicator of the quality and implementation of inquiry-based instruction is the level of the teacher's own inquiry skills and depth of knowledge of the nature of science. Even the best teachers struggle to successfully use inquiry-based approaches (Capps and Crawford, 2013) . In classrooms in which teachers are paired with science graduate students, instruction shifted to more inquiry-based approaches. The graduate students described the inquiry methods used in the classroom similar in overall structure to the inquiry methods used in their own labs suggesting increased authenticity (Gengarelly and Abrams, 2009) .

Increased authenticity and relevancy cultivates student engagement. Opportunities for students to collect and analyze data in local ecosystems helps them connect science content with the world around them and to ecological issues that are important where they live. Citizen science is a powerful way to engage students in scientific inquiry. Appreciation for the diversity of scientific fields and the rejection of the idea that science is an unchanging body of predetermined knowledge is strengthened through their participation. The National Science Foundation supports citizen science as a way to interest students in STEM disciplines and encourage them to progress in their science education (Green and Medina-Jerez, 2012) . These experiences have the potential to improve students' educational experiences in science education in order to encourage them to pursue science in their post secondary education and possibly careers (Jenkins, 2011).

The integration of ecological restoration and science education will develop scientific and environmental literacy in students, which is essential for future decision-making as a society. Environmental issues are growing in complexity, and it is critical for citizens to have the scientific background to understand problems and design solutions. Ecological restoration empowers students by providing them the opportunity to be proactive and to contribute to restoring ecosystems instead of simply learning about environmental issues while feeling powerless. Future stakeholders with environmental literacy will have the competency to take action in environmental activism, political activities, consumer choices, or ecosystem actions (McMillan and Vasseur, 2010; Short, 2010) .

The benefits of the integration of ecological restoration and science education address major problems and issues in both disciplines. Ecological restoration gains the ability to monitor restoration success through school citizen science networks and the enhancement of community engagement and acceptance of restoration projects. Science education gains authenticity and relevancy of science content, increased student engagement, and the development of scientific and environmental literacy. Ecological integrity and scientific literacy are essential to the future sustainability of the world's ecosystems as human demand increases and ecological issues increase in complexity and urgency.

References

Archambault, I., Janosz, M., Morizot, J., and Pagani, L. (2009). Adolescent behavioral, affective, and cognitive engagement in school: Relationship to dropout. *Journal of School Health, 79*(9), 408-415.

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T. S., Sierro, A., Watson, J. E. M., and Braunisch, V. (2010). From publications to public actions: When conservation biologists bridge the gap between research and implementation. *Bioscience, 60*(10), 835-842. doi:10.1525/bio.2010.60.10.10

Aronson, J., and Alexander, S. (2013). Ecosystem restoration is now a global priority: Time to roll up our sleeves. *Restoration Ecology, 21*(3), 293-296. doi:10.1111/rec.12011

Atkinson, R. D. (2012). Why the current education reform strategy won't work. *Issues in Science and Technology, 28*(3), 29-36.

Baer, S., Collins, S., Blair, J., Knapp, A., and Fiedler, A. (2005). Soil heterogeneity effects on tallgrass prairie community heterogeneity: An application of ecological theory to restoration ecology. *Restoration Ecology, 13*(2), 413-424. doi:10.1111/j.1526-100X.2005.00051.x

Baldi, S., Jin, Y., Skemer, M., Green, P.J., and Herget, D. (2007). *Highlights From PISA 2006: Performance of U.S. 15-Year-Old Students in Science and Mathematics Literacy in an International Context* (NCES 2008–016). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.

Beisner, B., Haydon, D., and Cuddington, K. (2003). Alternative stable states in ecology. *Frontiers in Ecology and the Environment, 1*(7), 376-382. doi:10.2307/3868190

Bell, R. L., Smetana, L., and Binns, I. (2005). Simplifying inquiry instruction: Assessing the inquiry level of classroom activities. *Science Teacher, 72*(7), 30.

Bradshaw, G., and Bekoff, M. (2001). Ecology and social responsibility: The re-embodiment of science. *Trends in Ecology and Evolution, 16*(8), 460-465. doi:10.1016/S0169-5347(01)02204-2

Brudvig, L. A. (2011). The restoration of biodiversity: Where has research been and where does it need to go? *American Journal of Botany, 98*(3), 549-558. doi:10.3732/ajb.1000285

Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F., and Rey-Benayas, J. M. (2011). Restoration of ecosystem services and biodiversity: Conflicts and opportunities. *Trends in Ecology and Evolution, 26*(10), 541-549. doi:10.1016/j.tree.2011.06.011

Burke, S. M., and Mitchell, N. (2007). People as ecological participants in ecological restoration. *Restoration Ecology, 15*(2), 348-350. doi:10.1111/j.1526-100X.2007.00223.x

Cabin, R. J. (2007). Science-driven restoration: A square grid on a round earth? *Restoration Ecology, 15*(1), 1-7. doi:10.1111/j.1526-100X.2006.00183.x

Cairns, J. (2000). Setting ecological restoration goals for technical feasibility and scientific validity. *Ecological Engineering, 15*(3-4), 171-180. doi:10.1016/S0925-8574(00)00068-9

Capps, D. K., and Crawford, B. A. (2013). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education, 24*(3), 497-526.

Choi, Y. D., Temperton, V. M., Allen, E. B., Grootjans, A. P., Halassy, M., Hobbs, R. J., Torok, K. (2008). Ecological restoration for future sustainability in a changing environment. *Ecoscience, 15*(1), 53-64. doi:10.2980/1195-6860(2008)15[53:ERFFSI]2.0.CO;2

Clean Water Act of 1972, 33 U.S.C. § 1251 et seq. (2002). Retrieved from http://www.epa.gov/agriculture/lcwa.html

Clewell, A., and Aronson, J. (2006). Motivations for the restoration of ecosystems. *Conservation Biology, 20*(2), 420-428. doi:10.1111/j.1523-1739.2006.00340.x

Clewell, A. F., Aronson, J., and Society for Ecological Restoration International. (2007). *Ecological restoration : Principles, values, and structure of an emerging profession*. Washington, D.C.: Island Press.

Comín, F. A. (2010). *Ecological restoration : A global challenge*. Cambridge, UK ;New York: Cambridge University Press.

Cooper, C. B., Dickinson, J., Phillips, T., and Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society, 12*(2), 11.

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., . . . Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment, 10*(6), 291-297. doi:10.1890/110236

Dobson, A., Bradshaw, A., and Baker, A. (1997). Hopes for the future: Restoration ecology and conservation biology. *Science, 277*(5325), 515-522. doi:10.1126/science.277.5325.515

Driver, R., Asoko, H., and Leach, J. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*, 5-12. doi:10.2307/1176933

Ehrenfeld, J. (2000). Defining the limits of restoration: The need for realistic goals. *Restoration Ecology, 8*(1), 2-9. doi:10.1046/j.1526-100x.2000.80002.x

Estuaries and Clean Waters Act of 2000,106 U.S.C. § S. 835. (1999). Retrieved from http://water.epa.gov/.

Falk, D. A., Palmer, M. A., Zedler, J. B., and Society for Ecological Restoration International. (2006). *Foundations of restoration ecology*. Washington, D.C.: Island Press.

Farris-Berg, K., and Tomorrow, P. (2008). *Inspiring the next generation of innovators: Students, parents and educators speak up about science education*. Project Tomorrow.

Featherston III, C. B. (2010). High school dropout prevention: A review of the literature. *Review of Higher Education and Self-Learning, 3*(7), 68-75.

Feinstein, N. (2011). Salvaging science literacy. *Science Education, 95*(1), 168-185. doi:10.1002/sce.20414

Fleischman, H.L., Hopstock, P.J., Pelczar, M.P., and Shelley, B.E. (2010). *Highlights From PISA 2009: Performance of U.S. 15-Year- Old Students in Reading, Mathematics, and Science Literacy in an International Context* (NCES 2011-004). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office.

Foley, J., DeFries, R., Asner, G., Barford, C., Bonan, G., Carpenter, S., . . . Snyder, P. (2005). Global consequences of land use. *Science, 309*(5734), 570-574. doi:10.1126/science.1111772

Gengarelly, L., and Abrams, E. (2009). Closing the gap: Inquiry in research and the secondary science classroom. *Journal of Science Education and Technology, 18*(1), 74-84. doi:10.1007/s10956-008-9134-2

Green, C., and Medina-Jerez, W. (2012). Project citizen: Promoting action-oriented citizen science in the classroom. *Science Teacher, 79*(9), 58-63.

Higgs, E. S. (2003). *Nature by design : People, natural process, and ecological restoration*. Cambridge, Mass.: MIT Press.

Hobbs, R. J. (2007). Setting effective and realistic restoration goals: Key directions for research. *Restoration Ecology, 15*(2), 354-357. doi:10.1111/j.1526-100X.2007.00225.x

Hobbs, R. J., and Cramer, V. A. (2008). Restoration ecology: Interventionist approaches for restoring and maintaining ecosystem function in the face of rapid environmental change. *Annual Review of Environment and Resources, 33*, 39-61. doi:10.1146/annurev.environ.33.020107.113631

Hobbs, R., and Harris, J. (2001). Restoration ecology: Repairing the earth's ecosystems in the new millennium. *Restoration Ecology, 9*(2), 239-246. doi:10.1046/j.1526-100x.2001.009002239.x

Hobbs, R., and Norton, D. (1996). Towards a conceptual framework for restoration ecology. *Restoration Ecology, 4*(2), 93-110. doi:10.1111/j.1526-100X.1996.tb00112.x

Hughes, F. M. R., Adams, W. M., and Stroh, P. A. (2012). When is open-endedness desirable in restoration projects? *Restoration Ecology, 20*(3), 291-295. doi:10.1111/j.1526-100X.2012.00874.x

Janosz, M., Archambault, I., Morizot, J., and Pagani, L. S. (2008). School engagement trajectories and their differential predictive relations to dropout. *Journal of Social Issues, 64*(1), 21-40. doi:10.1111/j.1540-4560.2008.00546.x

Jaunatre, R., Buisson, E., Muller, I., Morlon, H., Mesleard, F., and Dutoit, T. (2013). New synthetic indicators to assess community resilience and restoration success. *Ecological Indicators, 29*, 468-477. doi:10.1016/j.ecolind.2013.01.023

Jenkins, L. (2011). Using citizen science beyond teaching science content: A strategy for making science relevant to students' lives. *Cultural Studies of Science Education,* 6(2), 501-508. doi:10.1007/s11422-010-9304-4

Kanter, D. E., and Konstantopoulos, S. (2010). The impact of a project-based science curriculum on minority student achievement, attitudes, and careers: The effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Science Education, 94*(5), 855-887.

Kettlewell, C. I., Bouchard, V., Porej, D., Micacchion, M., Mack, J. J., White, D., and Fay, L. (2008). An assessment of wetland impacts and compensatory mitigation in the cuyahoga river watershed, ohio, USA. *Wetlands, 28*(1), 57-67. doi:10.1672/07-01.1

Landis, R. N. 1., and Reschly, A. L. 2. (2013). Reexamining gifted underachievement and dropout through the lens of student engagement. *Journal for the Education of the Gifted, 36*(2), 220-249. doi:10.1177/0162353213480864

McMillan, E., and Vasseur, L. (2010). Environmental education: Interdisciplinarity in action. *International Journal of Interdisciplinary Social Sciences, 5*(3), 435-445.

Millennium Ecosystem Assessment. (2005). *Millennium ecosystem assessment. ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

Miller, J. R., and Hobbs, R. J. (2007). Habitat restoration - do we know what we're doing? *Restoration Ecology, 15*(3), 382-390. doi:10.1111/j.1526-100X.2007.00234.x

Minner, D. D., Levy, A. J., and Century, J. (2010). Inquiry-based science Instruction—What is it and does it matter? results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496. doi:10.1002/tea.20347

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Newmann, F. M., and Wehlage, G. G. (1993). Five standards of authentic instruction. *Educational Leadership, 50*(7), 8-12.

Nie, Y., Tan, G. H., Liau, A. K., Lau, S., and Chua, B. L. (2013). The roles of teacher efficacy in instructional innovation: Its predictive relations to constructivist and didactic instruction. *Educational Research for Policy and Practice, 12*(1), *67-77*.

Ormerod, S. (2003). Restoration in applied ecology: Editor's introduction. *Journal of Applied Ecology, 40*(1), 44-50. doi:10.1046/j.1365-2664.2003.00799.x

Pace, M. L., Hampton, S. E., Limburg, K. E., Bennett, E. M., Cook, E. M., Davis, A. E., . . . Strayer, D. L. (2010). Communicating with the public: Opportunities and rewards for individual ecologists. *Frontiers in Ecology and the Environment, 8*(6), 292-298. doi:10.1890/090168

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., ... Turner, M. (2004). Ecology for a crowded planet. *Science, 304*(5675), 1251-1252. doi:10.1126/science.1095780

Palmer, M., Bernhardt, E., Allan, J., Lake, P., Alexander, G., Brooks, S., … Sudduth, E. (2005). Standards for ecologically successful river restoration. *Journal of Applied Ecology, 42*(2), 208-217. doi:10.1111/j.1365-2664.2005.01004.x

Partnership for 21st Century Skills. (2009). *P21 framework definitions.* Partnership for 21st Century Skills.

Peker, D., and Dolan, E. (2012). *Helping students make meaning of authentic investigations: Findings from a student-teacher-scientist partnership* Springer Science and Business Media B.V. doi:10.1007/s11422-012-9385-3

Preus, B. (2012). Authentic instruction for 21st century learning: Higher order thinking in an inclusive school. *American Secondary Education, 40*(3), 59-79.

Project Tomorrow. (2008). *Speak up 2007 for students, teachers, parents and school leaders: Selected national findings.* Project Tomorrow.

Rey Benayas, J. M., Newton, A. C., Diaz, A., and Bullock, J. M. (2009). Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. *Science, 325*(5944), 1121-1124. doi:10.1126/science.1172460

Ruiz-Jaen, M., and Aide, T. (2005). Restoration success: How is it being measured? *Restoration Ecology, 13*(3), 569-577. doi:10.1111/j.1526-100X.2005.00072.x

Schneider, R. M., Krajcik, J. S., and Marx, R. W. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching, 39*(5), 410-422. doi:10.1002/tea.10029

Shackelford, N., Hobbs, R. J., Burgar, J. M., Erickson, T. E., Fontaine, J. B., Laliberte, E., . . . Standish, R. J. (2013). Primed for change: Developing ecological restoration for the 21st century. *Restoration Ecology, 21*(3), 297-304. doi:10.1111/rec.12012

Short, P. C. (2010). Responsible environmental action: Its role and status in environmental education and environmental quality. *Journal of Environmental Education, 41*(1), 7-21. doi:10.1080/00958960903206781

Society for Ecological Restoration Science and Policy Working Group (SER International). (2004). *The SER international primer on ecological* *restoration*. Tuscon, AZ: Society for Ecological Restoration International.

Society for Ecological Restoration Science and Policy Working Group (SER International). (2005). *Guidelines for developing and managing ecological restoration projects*. Tuscon,AZ: Society for Ecological Restoration International.

Stohr-Hunt, P. (1996). An analysis of frequency of hands-on experience and science achievement. *Journal of Research in Science Teaching, 33*, 101-109. doi:10.1002/(SICI)1098-2736(199601)33:1<101::AID-TEA6>3.0.CO;2-Z

Suding, K. N. (2011). Toward an era of restoration in ecology: Successes, failures, and opportunities ahead. *Annual Review of Ecology, Evolution, and Systematics, Vol 42, 42*, 465-487. doi:10.1146/annurev-ecolsys-102710-145115

Suding, K., Gross, K., and Houseman, G. (2004). Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution, 19*(1), 46-53. doi:10.1016/j.tree.2003.10.005

Sudol, M., and Ambrose, G. (2002). The US Clean Water Act and Habitat Replacement: Evaluation of Mitigation Sites in Orange County, California, USA. *Environmental Management,* 30(5), 727-734. DOI: 10.1007/s00267-002-2787-3

Turner, S., and Peck, D. (2009). Can we do school science better? Facing the problem of student engagement. *Education Canada, 49*(2), 54-57.

Vitousek, P., Mooney, H., Lubchenco, J., and Melillo, J. (1997). Human domination of earth's ecosystems. *Science, 277*(5325), 494-499. doi:10.1126/science.277.5325.494

White, P., and Walker, J. (1997). Approximating nature's variation: Selecting and using reference information in restoration ecology. *Restoration Ecology, 5*(4), 338-349. doi:10.1046/j.1526-100X.1997.00547.x

Wyss, V. L., Dolenc, N., Kong, X., and Tai, R. H. (2013). Time on text and science achievement for high school biology students. *American Secondary Education, 41*(2), 49-59.