

OPINION ARTICLE

Insights from a Cross-Disciplinary Seminar: 10 Pivotal Papers for Ecological Restoration

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Abstract

Restoration ecology is a deepening and diversifying field with current research incorporating multiple disciplines and infusing long-standing ideas with fresh perspectives. We present a list of 10 recent pivotal papers exemplifying new directions in ecological restoration that were selected by students in a cross-disciplinary graduate seminar at the University of California, Berkeley. We highlight research that applies ecological theory to improve restoration practice in the context of global change (e.g. climate modeling, evaluation of novel ecosystems) and discuss remaining knowledge gaps. We also discuss papers that recognize the social context of restoration and the coupled nature of social and ecological systems, ranging from the incorporation of cultural values and Traditional Ecological Knowledge into restoration, to the consideration of the broader impacts of markets on restoration practices.

In addition, we include perspectives that focus on improving communication between social and natural scientists as well as between scientists and practitioners, developing effective ecological monitoring, and applying more integrated, whole-landscape approaches to restoration. We conclude with insights on recurrent themes in the papers regarding planning restoration in human-modified landscapes, application of ecological theory, improvements to restoration practice, and the social contexts of restoration. We share lessons from our cross-disciplinary endeavor, and invite further discussion on the future directions of restoration ecology through contributions to our seminar blog site <http://restecology.blogspot.com>.

Key words: climate modeling, coupled social and ecological systems, ecological monitoring, ecosystem services markets, global change, novel ecosystems, restoration practice, Traditional Ecological Knowledge.

Introduction

Restoration ecologists are increasingly responding to large-scale ecosystem change. As a result, a broader range of stakeholders are being incorporated into the restoration process, thus necessitating enhanced communication across disciplines. As members of a cross-disciplinary graduate seminar on restoration ecology, we present a list of 10 recent pivotal papers that stimulated discussion on new directions in the field. Our seminar group included environmental scientists, geographers, landscape architects, and environmental planners; many of us have also worked as restoration practitioners. To select the papers presented here, we collectively read and critiqued 99 articles from 46 journals (Table 1).

From these papers, seminar participants created "Top 10" lists of recent papers (primarily peer-reviewed journal articles published between 2008 and 2010) that highlighted exciting and essential developments in the field. The authors then synthesized those lists into the 10 papers we present below (Fig. 1). Topics represented in the final list fell into four overarching themes emphasized throughout our seminar and reflected in individual lists: assessing and managing novel ecosystems, applying ecological theory to restoration, improving restoration practice, and considering social factors impacting restoration (Table 2). We gave preference to papers that occurred frequently on individual lists while avoiding significant topic overlap. We also prioritized topics that received considerable discussion during our seminar, even if they were not well-represented in the individual lists.

We acknowledge that 10 papers cannot cover the full range of innovations occurring in the field. Rather, our intent is for this brief list to offer our evaluation from a fresh, cross-disciplinary perspective and encourage further discussion among restoration ecologists, social scientists, planners, designers, and practitioners.

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Bradley et al., "Climate Change and Plant Invasions: Restoration Opportunities Ahead?" 2009, in *Global Change Biology*

Using bioclimatic envelope modeling, Bradley et al. (2009) predict how climate change will affect the future distribution of widespread invasive plant species. While the ranges of some species will expand, others will contract, leaving previously invaded regions as "retreat areas" with high restoration potential. By applying habitat modeling to non-native species, Bradley et al. demonstrate how global climate change may create time-sensitive opportunities for restoration strategies that use both native and non-native species. As one restoration practitioner in our seminar wrote, "Before [we] jump into response mode ... we need to consider whether this weed will be a problem and priority under future conditions." This kind of "outside of the box" thinking was highly regarded among seminar participants and challenged us to rethink the traditional restoration target of returning systems to a "historic" condition.

Chazdon et al., "Beyond Reserves: A Research Agenda for Conserving Biodiversity in Human-Modified Tropical Landscapes." 2009, in *Biotropica*

Chazdon et al. (2009) present an integrated, cross-disciplinary approach to conservation in human-modified "matrix" landscapes, including urban and agricultural areas. Although focused on the tropics, the outlined agenda is widely applicable across regions. The authors argue that effective biodiversity conservation must consider ecological, social, cultural, political, and economic processes. They also acknowledge trade-offs between the varied goals held by different stakeholder groups. Furthermore, they recognize that interactions between these complex factors affect biodiversity conservation, ecosystem service provisioning, and the sustainability of rural livelihoods. This paper was a "weekly winner" in our seminar (Fig. 1) because it offers a broad, cross-disciplinary framework aimed at unifying the often disparate goals of agriculture and conservation. In addition, it reflects the ongoing shift in conservation paradigms of looking beyond protected areas and considering restoration opportunities within the intervening matrix.

Flitcroft et al. "Social Infrastructure to Integrate Science and Practice: the Experience of the Long Tom Watershed Council." 2009, in *Ecology and Society*

This paper presents a case study in which diverse stakeholders worked together to design and implement collaborative watershed restoration projects. Describing the Long Tom Watershed Council in Oregon, Flitcroft et al. (2009) characterize "putting science into practice... [as]... a complex social-ecological process," which required outreach to skeptical stakeholders. The authors emphasized allowing room for differences in

Table 1. Source journals for papers read and critiqued by individual participants (the number in parentheses indicates how many articles were read from that journal).

Restoration Ecology (14)
Journal of Applied Ecology (8)
Frontiers in Ecology and Environment (6)
Trends in Ecology and Evolution (6)
Ecological Applications (4)
Ecological Economics (4)
Biological Conservation (3)
Bioscience (3)
Conservation Biology (3)
Ecology and Society (3)
Proceedings of the National Academy of Sciences (3)
Annual Review of Environment and Resources (2)
Ecography (2)
Ecological Complexity (2)
Environmental Management (2)
Landscape and Urban Planning (2)
Plos One (2)
Science (2)
Agriculture Ecosystems & Environment (1)
Biological Invasions (1)
Biotropica (1)
Canadian Journal of Fisheries and Aquatic Sciences (1)
Ecological Restoration (1)
Ecology (1)
Ecology Letters (1)
Ecoscience (1)
Ecosystems (1)
Environmental Ethics (1)
Environmental Research Letters (1)
Environmental Science & Policy (1)
Forest Ecology & Management (1)
Freshwater Biology (1)
Global Change Biology (1)
Global Environmental Change: Human and Policy Dimensions (1)
Human Organization (1)
Journal Of Ecology (1)
Land Use Policy (1)
Landscape Ecology (1)
Ocean & Coastal Management (1)
Oikos (1)
Perspectives in Plant Ecology Evolution and Systematics (1)
Policy Sciences (1)
Rangeland Ecology & Management (1)
River Research and Applications (1)
Society & Natural Resources (1)

Critiques are available at <http://restecology.blogspot.com/>.

people's values about how to protect a watershed, ensuring transparency with information sharing, and translating science into layperson's terms. Data collection facilitated community outreach, giving stakeholders a sense of ownership over and faith in the data collected, as well as common experience with other stakeholders. Social infrastructure that brings local citizens together is required to cultivate and support this level of stakeholder investment. This paper was a seminar favorite because it provides a concrete example of a project that included extensive citizen participation, and successfully integrated restoration science with on-the-ground practice.

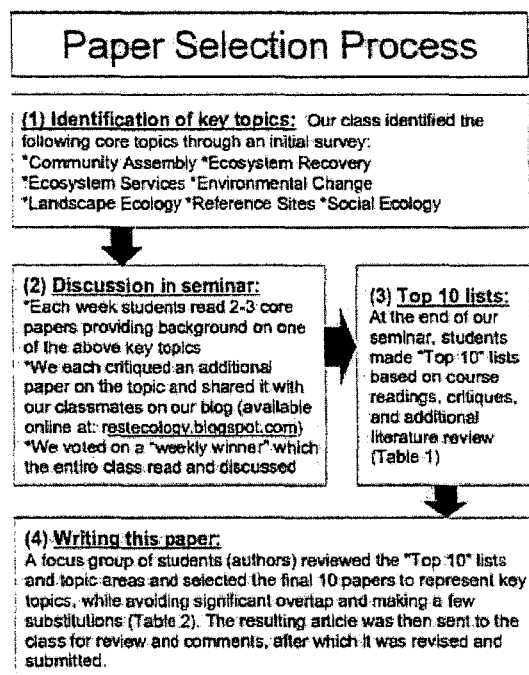


Figure 1. Flow chart outlining the process of selecting 10 pivotal papers.

Funk et al., "Restoration through Reassembly: Plant Traits and Invasion Resistance." 2008, in *Trends in Ecology & Evolution*

Funk et al. (2008) suggest that a trait-based community assembly framework can strengthen the resistance of natural areas to invasion by non-native species. Building on ideas from community assembly, including limiting similarity, habitat filtering, and niche occupancy, Funk et al. provide several insights for on-the-ground restoration designs. Notably, restoration managers should re-vegetate with plants that are functionally similar to potential invasive species, thus limiting empty niches and preempting the establishment of non-native species. Seminar participants appreciated the emphasis on matching the functional traits of restored communities with prospective invaders because it is a proactive, theory-based approach to managing invasion. Although the effective use of this approach may require a great deal of scientific knowledge (e.g. comprehensive trait data) that is not yet available, we believe it holds considerable promise.

Garibaldi and Turner, "Cultural Keystone Species: Implications for Ecological Conservation and Restoration." 2004, in *Ecology and Society*

Garibaldi and Turner (2004) introduce the concept of "cultural keystone species" as a metaphorical parallel to ecological keystone species and a starting place for the restoration of coupled social-ecological systems. The authors provide criteria and examples identifying culturally significant species which play a key role in defining the cultural identity of a people, but may or may not be considered ecologically dominant. We selected this paper for its thoughtful perspective on including

multiple knowledge systems in our understanding of restoration priorities. It particularly speaks to building partnerships between Traditional Ecological Knowledge (TEK) and Western scientific knowledge, as well as between social science and natural science, topics which emerged frequently in seminar discussions. The paper encouraged us to ask: what happens to a culture when the landscape is modified? Also, what happens to the landscape when cultural management practices change or adapt? This paper is an exception to our 2008–2010 criterion because most recent scholarship on the topic is published in book form. We felt that this paper is one of the best recent journal articles on the topic of TEK which is both introductory and gives concrete examples.

Hobbs et al., "Novel Ecosystems: Implications for Conservation and Restoration." 2009, in *Trends in Ecology & Evolution*

Increased biotic change (e.g. invasion and extinction) and abiotic change (e.g. land abandonment and climate change) are driving the formation of new, non-historic species assemblages. These assemblages are considered "novel ecosystems" when they cross a threshold after which they cannot return to their historic state. Hobbs et al. (2009) suggest that traditional restoration be reserved for systems that have not crossed this threshold, and novel ecosystems should instead be assessed and managed for specific functions. They highlight that non-native species can become important components of novel ecosystems by providing ecosystem services, such as habitat for desired species. This paper encouraged us to make more realistic assessments about which invasive species can be successfully removed from restoration sites, and which of those should be removed based on expected effects on desired species and ecosystem functions. It also reveals restoration as a field facing a situation in which all the rules are changing, thereby emphasizing the importance of flexible thinking. This paper was very popular in our seminar and appeared on nearly all of the individual "Top 10" lists.

Lave, R., M. Doyle, and M. Robertson. "Privatizing Stream Restoration in the US." 2010, in *Social Studies of Science*

Lave et al. (2010) address the relationship between ecological restoration, ecosystem service markets, and environmental regulation using a case study of stream restoration. The authors highlight how neoliberal practices—the push toward market-based environmental management—are shifting how ecological restoration is conceived and practiced. They argue that this shift is creating demand from regulatory and financial institutions for restoration science that can (1) "be taught as a standardized package;" (2) "be used by agencies to justify decisions;" and (3) "form the basis for new ecosystem service markets." Because of this, the standardized, commercialized, and increasingly well-disseminated knowledge claims of the

Table 2. Broad issues and subcategories that were prioritized by our restoration ecology seminar, coverage of which was used to select the final 10 papers.

<i>Improving Restoration Practice</i>	<i>Applying Ecological Theory to Restoration</i>
Defining Reference Sites (Hobbs)	Community Assembly (Funk)
Monitoring (Flitcroft, Lindenmayer, Lundholm)	Landscape Ecology (Chazdon, Palmer)
Linking Ecosystem Theory and Restoration Practice (Flitcroft, Funk, Palmer)	Ecological Modeling (Bradley)
Addressing Invasive Species (Bradley, Funk, Hobbs, Lundholm)	Species Recovery (Chazdon)
<i>Planning Restoration in Human-Modified Landscapes</i>	<i>Considering Social Factors Affecting Restoration</i>
Urban Ecology (Lundholm)	Ecosystem Services (Chazdon, Garibaldi, Hobbs, Lave)
Agroecology (Chazdon)	Coupled Social and Ecological Systems (Chazdon, Flitcroft, Garibaldi, Lave)
Climate Change (Bradley, Hobbs)	Multiple Knowledge Systems (Flitcroft, Garibaldi)
	Privatization of Restoration (Lave)

Papers are referred to by first author.

private sector are shifting the balance of power and claims on bureaucratic and financial legitimacy from public institutions to private firms. We chose this paper, highlighting the ongoing privatization of stream restoration in the United States, because it demonstrates how understanding political-economic relations is critical for understanding ecological restoration. This issue of socioeconomic context was a frequent discussion topic in our seminar.

Lindenmayer and Likens, "Adaptive Monitoring: A New Paradigm for Long-Term Research and Monitoring." 2009, in *Trends in Ecology & Evolution*

Adaptive management has become well known as an iterative and flexible strategy for land management that incorporates ongoing research. "Adaptive monitoring" is proposed as an efficiency-enhancing complement to adaptive management. Lindenmayer and Likens (2009) advocate long-term monitoring programs that will improve understanding of ecological processes. The proposed vision incorporates thoughtful experimental design and conceptual frameworks as tools to focus research questions and promote meaningful data collection. Many students in our seminar were concerned that funding for monitoring is often short-term and politically motivated, and extended monitoring for critical project evaluation is frequently neglected. We selected this paper because Lindenmayer and Likens draw attention to this dilemma, and provide concrete steps for designing effective monitoring programs based on a real-world case study.

Lundholm, J. T. and P. J. Richardson. "Habitat Analogues for Reconciliation Ecology in Urban and Industrial Environments." 2010, in *Journal of Applied Ecology*

"Reconciliation ecology" targets habitat and species protection in urban and industrial landscapes. Lundholm and Richardson

(2010) argue that urban habitats contain analogues to pre-industrial habitats, which can enable industrial landscapes to play an important role in supporting biodiversity. For instance, hard-surfaced habitats such as walls or quarries may be analogous to rock cliffs, and thus be able to support diverse species adapted to rocky habitats. Furthermore, the authors argue that ecological engineering and/or assisted dispersal may assist with bringing diverse species into urban habitats, as a form of novel ecosystem. We chose this paper because it is especially useful for restoration practitioners and landscape architects developing ecological restoration designs in urban and industrial ecosystems.

Palmer, "Reforming Watershed Restoration: Science in Need of Application and Applications in Need of Science." 2009, in *Estuaries and Coasts*

Palmer (2009) suggests that the failure of many restoration projects reflects the wide disconnect between scientists and restoration practitioners. She explores the consequences of this gap using watershed restoration as a case study. She admonishes scientists to test well-established restoration practices. Conversely, she urges restoration practitioners to utilize more principles from ecological theory. She calls on both groups to reform their agendas and be flexible. By identifying areas of mutual interest for both scientists and restoration practitioners, including alternate stable states, scale dependency, and the relationship between diversity and stability, Palmer provides a road map for increasing cooperation, which can ultimately lead to more successful restoration projects. This paper was popular in our seminar, reflecting our consensus that cooperation is an essential agenda item for the future of restoration.

Conclusions

Important themes and challenges emerged from these papers, shaping our group's discussions. First, ecological and social

theories are important foundations for restoration. Scientists are still learning how complex, dynamic ecosystem processes function at multiple spatial scales. As a result, large gaps remain in the information needed to guide decision-making processes. While ecologists may help in filling such information gaps, considering multiple knowledge systems can also provide important insights (Garibaldi & Turner 2004; Flitcroft et al. 2009). Future research promises to turn conventional interpretations of ecological theory on their head, as when Bradley et al. (2009) suggested that climate change may create opportunities to control the distributions of invasive species and Hobbs et al. (2009) highlighted the potentially valuable services non-native species may provide in novel ecosystems. Our seminar group's consensus was that "outside of the box" creative thinking from multiple disciplines is necessary to address the complex global and local processes affecting ecosystem function.

Another major challenge we recognized was a disconnect between ecological theory and on-the-ground application. Our seminar group saw restoration as a young science in which the theory and practice should be co-evolving. For example, Funk et al. (2008) emphasized the role of ecological theory in informing restoration practice. Nonetheless, theoretical applications do not always trickle down from the academic literature to practitioners, and lessons from practitioners do not always inform research (Palmer 2009). More cross-pollination between practice and science is necessary. We especially see a need for restoration applications that are focused on human-modified matrix habitats, that is, ecosystems within actively managed or developed areas (Chazdon et al. 2009; Lundholm & Richardson 2009).

Complex relationships within coupled social and ecological systems set the broader context for restoration. The interactions between social, political, and economic processes dictate the terms of a restoration project, through funding incentives, social values around privatization of land and resources, or power dynamics among decision makers with different worldviews (Lave et al. 2010). The goal-oriented nature of restoration is complicated, as interventions are based on anthropocentric definitions of a "desirable state." Restoration ecologists need to be more aware of the policy incentives driving restoration decisions and need to get involved in policy making (Chazdon et al. 2009; Lindenmayer & Likens 2009; Palmer 2009). Complex ecological and social processes interact, and we need to bring social science together with ecology to better understand the human contexts of restoration.

The ability to address these issues is impeded by communication barriers between social scientists, natural scientists, designers, and planners. While disciplinary knowledge is still critical to solving thorny environmental problems, we benefited greatly in sharing perspectives from different disciplines. By discussing current issues in restoration ecology throughout the semester, our group was able to develop a shared vocabulary, allowing us to begin to break through disciplinary boundaries and achieve greater understanding of complex restoration challenges. Our seminar experience highlighted the

need to address gaps between science and practice and step up our communication efforts beyond scientific publications, e.g. through open access journals and popular literature, as well as communicating with visuals and graphics.

It is in this spirit of encouraging communication that we invite you to visit our graduate seminar blog, where we offer cross-disciplinary perspectives on current issues for restoration and present our paper critiques. It is our hope to provide an avenue for more collaboration and communication among designers, planners, and practitioners, as well as restoration ecologists. What 10 papers would you choose? Please join our conversation.

Implications for Practice

- Successful restoration requires creative, cross-disciplinary thinking. A comprehensive approach is needed to address social, political, and ecological aspects of a study site; ongoing global change and moving restoration targets; and opportunities for translating ecological theory into practice.
- Our graduate seminar stimulated communication among ecologists, social scientists, and restoration practitioners. We believe that this type of teamwork is essential for successful restoration. We provide a forum to encourage collaborative discussions at <http://restecology.blogspot.com/>

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