ON THE NEED FOR INNOVATION IN ECOLOGICAL RESTORATION[1]

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Abstract

Society has high expectations regarding the potential of ecological restoration to help confront the global environmental crisis, but the huge gap between restoration science and practice may undermine the recovery of native ecosystems in vast areas of degraded lands. In this paper, we explore the potential application of an innovation approach to bridge the gap between knowledge and action in restoration. The most promising innovation strategy for restoration is the adaptation of solutions developed in other fields of activity, for which market forces have historically supported programs of research and development. However, innovations in restoration may not rely only on technological tools requiring high investments. Rather, there are many opportunities for making better use of the existing funds and for low-cost solutions if restoration science and practice are reframed and integrated. If research projects are conceived to promote a co-production of knowledge with end users, valuable solutions for restoration problems may arise without extra investments. For restoration practice, substantial advances in our capacity to revert degradation could be obtained by shifting the focus from plot-scale, expensive solutions to the promotion of natural regeneration in sites where it is ecologically viable and socioeconomically feasible. For capacity building, promising approaches include emulating other models of technology transfer, mainly those used in agriculture, and fostering the use of web-based solutions. For governance, we recommend the promotion of "policy triggers" and better use of technology to obtain and integrate information. Finally, multi-stakeholder coalitions may contribute by linking these different fields of restoration and promoting the co-creation of solutions in complex socio-ecological systems. Large-scale restoration will not be achieved by the simple sum of small-scale projects implemented by traditional restoration approaches, so innovation can play an utmost role to fulfill the decades-old promise of restoration to reverse degradation at the landscape scale.

Key words: Capacity building, cost-effective restoration, restoration ecology, restoration governance, restoration policy.

Ecological restoration is an emergent human endeavor, which is aligned with other strategic activities to achieve the sustainable development goals of the United Nations, seeking to end poverty, repair Earth's vital processes, ensure the persistence of biodiversity, and improve the quality of life for all (Aronson & Alexander, 2013; Suding et al., 2015; Chazdon et al., 2016). Once degraded ecosystems are restored, their provisioning of services, such as soil and watershed protection, and climate regulation, is reinforced (Bullock et al., 2011). Society has a great expectation about the use of restoration to face some of the most critical problems brought by the contemporary global environmental crisis. However, there are several barriers holding back the potential of restoration to shape a better future.

In general, a relevant limitation in the Information Age is the fact that academic advances have not been adequately translated to practice (for restoration, see Clewell & Aronson, 2006) and that practice has advanced without benefiting from the full potential of science and technology to improve human activities. This limitation is exacerbated in ecological restoration, where practices go exactly in the opposite direction of the general approach that humans have used to shape the Earth: simplifying complex systems. A wealth of expertise and technology is available to foster simplification at large spatio-temporal scales, such as deforestation, wood production in industrial monoculture tree plantations, modern dietary patterns focused on very few staple food crops, and many other different aspects inherent to "western civilization," which has promoted a massive homogenization of culture, behavior, and all other fields of human experience. Rather, restoration seeks to increase complexity, facing the challenge of dealing with diversity, which has been frequently seen as a "problem" to manage modern systems. If a farmer wants to produce timber in monoculture tree plantations, one may find readily available technological packages, but if the goal is to grow just a few more species in the system, then few solutions are available and the majority of risks involved have to be internalized by the farmer. Appropriate knowledge is needed to support solutions for dealing with complexity, opening an opportunity for innovation in ecological restoration.

In this paper, we will advocate for innovation for advancing with ecological restoration globally. We explore how an innovation approach could be applied to ecological restoration and present some innovation

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perspectives of this approach in restoration science, practice, capacity building, governance, and the links among these fields. Finally, we provide specific recommendations to promote innovation in the context of restoration.

A Place for Innovation in Restoration

Innovation is focused on bringing new products, processes, and forms of organizations into economic and social use, which affects the system's behavior and the performance of institutions. Thus, innovation is viewed in a social and economic sense and not purely as discovery and invention (World Bank, 2006). This definition implies that innovation is neither science nor technology, but the application of knowledge of all types to achieve desired social and economic outcomes (World Bank, 2006). Innovation has been part of human history ever since we started to use tools and domesticate wild plants and animals. Although innovation accelerated after the Industrial Revolution and, more recently, in the Technological Revolution, its basic premise remains the same: using human creativity to solve problems. Ecological restoration has many unsolved problems (e.g., Perring et al., 2015), but an innovation approach has not been used yet in its full potential to find solutions in this field of activity, especially when it comes to improving restoration governance and cost-effectiveness. Understanding the basic principles of an innovation approach may be a first step for restoration professionals to shift the way they produce and use knowledge in order to achieve the best outcomes.

Innovation has been characterized by the following steps: (1) a "trigger"—some factor that compels changes of the status quo into something new; (2) a "breakthrough"—a foresight idea that brings the answer for a question/problem stated by the "trigger"; and (3) a "virality"—which results in a spreading success of the "breakthrough." The triggers of innovation could be market, policy, knowledge, or resource driven; often these triggers do not act alone but tend to interact (World Bank, 2006). The last two triggers correlate with the "breakthrough" factor, whereas market and policy are problem-oriented innovation triggers. Market, also called "demand pull," is a powerful trigger for innovation, where institutions tend to drive innovation toward the areas of greatest financial prospect. However, areas of greatest human need are frequently ignored (e.g., neglected diseases or crops) and extant institutions do not adequately govern their activities avoiding negative externalities, such as the well-known ecosystem degradation by some industrial activities (Anadon et al., 2016). Ecological restoration has been usually ignored by markets, with the few exceptions of environmental mitigation (Richardson, 2016) and carbon offsets (Galatowitsch, 2009). However, the prominent international mobilization to support large-scale restoration may shift this scenario, with an increasing flow of financial investments to recover ecological and socioeconomic functionality of vast degraded territories (Menz et al., 2013).

Knowledge and resource triggers partly occur in "breakthroughs" originated by serendipity—a "happy accident"—or arise from research and development (R&D) investments. Serendipity and R&D are not independent, since serendipity can happen in groups where a "critical mass" of multidisciplinary scientists works together in an environment that fosters communication and where the work and the interest of a researcher can be shared with others who may find a new application for a new knowledge. Although ecological restoration has many "triggers" of innovation, resulting from the combination of its frequent failures and growing expectancies for more effective, larger-scale, and long-lasting interventions, the allocation of resources for pushing an innovation agenda for restoration is absent or very limited compared to other profitable activities attracting massive investments for their constant improvement and transformation, like medicine, industrial agriculture, and industry. However, there are many opportunities for making a better use of the existing funds and for low-cost solutions if restoration science and practice are reframed to proactively search for innovations. One potential solution is the adaptation of technologies developed in other fields of activity, which requires fewer financial investments than creating something entirely new (Fig. 1).

The development of apps and gadgets, for instance, has been a major source of profound modifications in the functioning of urban societies, with an extremely fast "viralization" of innovations. However, the power of apps and gadgets alone to improve restoration programs is quite limited. Organizational culture has a massive influence on creativity and innovation. The main determinants to increase the occurrence of these "breakthroughs" of creativity are team cohesion (strategy focused), supervisory encouragement (encouragement of innovation behavior), challenge, resources, autonomy, and openness to innovation (Martins & Terblanche, 2003; Nybakk & Jenssen, 2012). In general, increasing the creativity in restoration projects is correlated with investment in an entrepreneurial behavior encouragement. Since entrepreneurship has become a tool for economic development, over the last decade, many member countries of the Organization for Economic Co-operation and Development (OECD) have introduced

Figure 1. Examples of innovations in restoration resulting from adapting technologies developed in other fields of activity. —A. Seedling production. An organic residue shredder adapted to extract seeds from dry fruits of native trees, in which its blades were substituted by thick rubber bands to break the fruits, instead of cutting them. Further, seeds are separated from broken fruits using a sieve. —B. Restoration implementation. Adaptation of agricultural sowing machines for direct seeding of native woody species with high operational efficiency and low costs, as an alternative to traditional costly restoration plantations (Durigan et al., 2013). Photo by Christian Knepper; image courtesy of Instituto Socioambiental. —C. Restoration monitoring. Using drones to monitor vegetation structure in tropical forest restoration, in which data obtained from drones are calibrated with field data to remotely assess ecological indicators such as canopy cover and biomass (Zahawi et al., 2015). Image courtesy of Jonathan Dandois.

Table 1. Enabling factors and recommendations to foster innovation in ecological restoration.

Key factors favor an innovative environment
• Freedom/autonomy of academia at early-stage research for innovation. Thus, autonomy of basic science favors the "serendipity" events.
• Environmental policies focus on outcomes and not on process, thus environmental policies would induce investment in environmental research and development, with a positive effect on the innovation process.
• Presence of clusters of innovation instead of isolated groups (constant and fast communication among groups).
• Presence of role models, which encourages vigorous competition among groups.
• Encouragement of risk taking, which seems critical in order to boost creativity. People are more likely to produce unusual, useful ideas if they receive: (1) supportive evaluation of new ideas; (2) recognition of their creativity; and (3) "forgiveness" of their unsuccessful ideas.
Proposals to close the gap between knowledge and action[1]
• General goals driven by "solutions to problems" instead of generalities like "further understanding of problem." Therefore, research projects based on/oriented by problems of decision makers and research users.
• Presence of facilitation agents, in order to organize the boundary between academics and research users. Continual engagement among communities, policy makers, non-governmental organizations, and researchers could be reached by periodic informal arenas, reinforcing these networks with flexibility.
• Recognition that scientific research is just one "piece of the puzzle," that knowledge is co-created by all project members into action.
• Mutual trust, managing asymmetries of power between organizations and individuals.
• Research projects are also designed for learning, thus failures must be expected and embraced, learning with them.

[1] Proposals based on Kristjanson et al. (2009).

policies that use entrepreneurship as an essential tool for sustainable development (see OECD, 2003). Understanding the key factors for creating a favorable environment for innovation and bridging the gap between knowledge and action is essential to promote it in the context of ecological restoration (Table 1).

The most influential socio-cultural factors for entrepreneurship have been the social stigma toward entrepreneurial failure (Vaillant & Lafuente, 2007), which represents a limiting factor in the context of ecological restoration. Most restoration projects have been implemented to comply with legal regulatory frameworks, in which restoration is seen as a kind of punishment to compensate environmental damages. In this context, individuals and organizations in charge of implementing mandatory restoration projects have limited freedom to test new restoration approaches and may prefer the traditional ones, with little or no modification of the existing technological packages, in order to prevent problems with the law (Brancalion et al., 2016a). Although the need to safeguard society's interests in restoration projects implemented to compensate environmental damages is justified (Maron et al., 2012) and requires innovations in terms of developing new legal instruments for this purpose (Chaves et al., 2015; Palmer & Ruhl, 2015), it will be difficult for restorationists to innovate if this activity does not expand beyond legal compliance.

Restoration innovations have to be deeply nested within the governance structures and socio-ecological complexities of the system in which the innovation is conceived and adopted. In the context of restoration, innovation has to be heavily process-oriented and go beyond the punctual development of technological tools. In the next section, we will present reflections and explicit examples on how innovation can be developed for the main fields of activity of restoration, aiming at demonstrating the diverse opportunities restoration offers to inventive people and to stimulate a timely reflection on the role of academics to help transform the restoration world.

Innovation Perspectives for Ecological Restoration

Restoration is changing fast, moving from a field of applied ecology to a much broader strategy to foster sustainable development, so the innovations developed today should target the key problems expected in the near future, taking into consideration the challenges of changing decision making in complex socio-ecological systems. In order to facilitate the comprehension of the application of an innovation approach to restoration, we present a critical overview and examples of innovation in restoration science, practice, capacity building, and governance, and we discuss how to link these fields, foreseeing the trends expected for the near future.

Innovation in Restoration Science

A large portion of the knowledge generated so far by restoration ecology may not drive innovations,

Figure 2. Investigating biophysical and socioeconomic drivers of natural regeneration to develop software for restoration prioritization. Natural regeneration in a human-modified tropical landscape of Brazil. The development of prediction models to infer regeneration probabilities in areas not covered by native forests were possible due to the data availability and biophysical analysis on forest regeneration over the past 20 years in human-modified landscapes of southeastern Brazilian. Based on estimation models, it has been possible to model restoration costs at watershed scales to prioritize investments based on the cost-effectiveness of different alternatives. The knowledge basis developed by this project, together with other databases focused on the potential of ecosystem services provisioning of each landscape portion, has been used to develop a plugin of a conservation prioritization software to support large-scale forest restoration with high cost-effectiveness for different expected outcomes. Photo by Pedro H. S. Brancalion.

because the scales and levels of complexity in which knowledge is developed versus adopted do not match. Although the "plot-based" approach may help to advance restoration ecology by reducing the undesirable influence of non-controlled factors in hypothesis testing, it is a limitation for the application of the knowledge generated in on-the-ground restoration projects, operating in much more complex socio-ecological systems than observed in controlled experimental conditions (Holl, 2017). Thus, restoration research also has to embrace complexity in order to be useful for innovation, and it has to be developed closer to end users to be better grounded in the right questions and problems. Dealing with complexity is crucial to operationalize restoration efforts in dynamic and multifunctional landscapes, in which decisions are made considering several biophysical and socioeconomic factors operating at multiple spatial and temporal scales.

Applying an innovation approach to restoration science may not imply additional costs. Funding agencies may simply reframe their calls for proposals to promote the generation of knowledge with better chances of application, and governments, private organizations, and non-governmental organizations (NGOs) can be in charge of funding the sequential activities further required to transform scientific findings into practical solutions, in an integrated and continuous processes of innovation development involving multidisciplinary teams and multi-stakeholder partnerships (Fig. 2). This approach has already been adopted in engineering projects, and could be adapted to the context of ecological restoration. However, the knowledge basis promoted by scientific research is only one component of the innovation, which has to be developed as a co-production between researchers and end users.

INNOVATION IN RESTORATION PRACTICE

Changes in restoration practice will require changes in restoration mindset. Current mindset emphasizes high levels of human control over ecosystems undergoing restoration, with a strong focus on the ecological benefits from this activity. Consequently, the prevalent restoration mindset requires high investments of energy, time, and money to change a system in the short term and shape it to a highly specified ecological endpoint, and this mindset has limited openness for approaches promoting some form of economic use. As a consequence, formal programs have invested large amounts of funds in

Figure 3. Interplanting *Eucalyptus* L'Hér. with native tree species to pay off implementation costs by timber exploitation. Plantation of *Eucalyptus* with mid- and late-successional native trees in the Atlantic Forest of Brazil. In spite of the positive ecological outcomes obtained by high-diversity restoration plantations in the threatened Atlantic Forest of Brazil (see Rodrigues et al., 2011), their high costs and limited potential to generate income have made them a non-attractive option to farmers. Interplanting *Eucalyptus* with mid- and late-successional native forest tree species has been tested as a new approach to reduce restoration implementation costs and obtain income from forests undergoing restoration. *Eucalyptus* seedlings are much cheaper and require lower maintenance interventions than native pioneer species and provide income from timber harvesting after five to seven years. The expectation is that the profit obtained by selling *Eucalyptus* will offset restoration costs and create a more favorable economic condition for supporting investments in the large-scale restoration of the Atlantic Forest (Brancalion et al., 2012). Photo by Pedro H. S. Brancalion.

active restoration approaches without foreseeing any direct economic benefits for landowners, while natural regeneration has been underused (Chazdon, 2017). Although innovations could play a role to improve current restoration practices, the most promising innovations in restoration practice for upscaling programs have to be conceived based on a different mindset, in which restoration interventions are planned to maximize its cost effectiveness.

The development of new technologies has to be focused on reducing restoration costs and increasing its direct economic benefits; ideally, both approaches can be combined to achieve higher economic viability of projects. Cost reductions can be obtained mainly by developing technologies that allow for a better use of natural regeneration in restoration programs or that modify active restoration approaches to reduce their implementation costs, such as using direct seeding instead of seedling plantations. In parallel, restoration has to be planned to allow some form of direct economic benefit to landholders, such as allowing the exploitation of timber (Fig. 3) and non-timber forest products and payments for ecosystem services (Brancalion et al., 2012). In brief, the restoration mindset will have to shift from the strict recovery of a native ecosystem to the establishment of a new economically viable land use, and restoration practices will have to explore the costs and economic benefits of different approaches to support decision-making.

INNOVATION IN RESTORATION CAPACITY BUILDING

Capacity building in restoration has been promoted essentially by NGOs and some governments based on traditional knowledge transfer approaches, using personal meetings, field visits, and primers as educational tools. These training and capacitating approaches tend to have high costs for traveling, organizing logistics, paying instructors, and printing educational materials, likely with a low number of engaged stakeholders, considering that landowner engagement is linked to their private benefits (e.g., Januchowski-Hartley et al., 2012). One opportunity is to emulate models of technology transfer adopted by agriculture organizations. For instance, instead of simply saying that a new seed is better and distributing some brochures describing the expected benefits, these organizations establish pilot sites in the regions where they want to disseminate the new technology, convince leaders of communities to pioneer the use of the new seeds in order to further influence other people, provide solid information on financial and other benefits to farmers, and offer the necessary knowledge and instrumental support for the adoption of the technology. When restoration adopts a similar approach, investments in capacity

Figure 4. Web-based systems for restoration capacity-building. Field course on forest and landscape restoration in Armenia, Colombia, coordinated by the Environmental Leadership and Training Initiative (ELTI). ELTI has promoted several capacity-building field courses on tropical forest restoration in Latin America and Southeast Asia (<http://elti.yale.edu/field-training-program>). These courses have successfully engaged local stakeholders and promoted best practices in specific regions, but this approach has evident restrictions to up-scaling capacity building. As a complementary approach, ELTI developed an online training program, in which professionals from different countries participate in sequential teaching modules, using a web-based training platform (<http://elti.yale.edu/online-training-program>). Activities include lectures taught by ELTI partners, live discussion sections, practical homework exercises, videos, and supplemental readings. Courses have been offered in English, Portuguese, and Spanish. Photo by Pedro H. S. Brancalion.

building tend to achieve much higher effectiveness (e.g., Richards et al., 2015).

Another valuable approach is to take advantage of social media and web-based systems (Fig. 4). Contrary to traditional capacity-building approaches used in restoration, social media has the potential to reach millions of people, at a much lower cost per person trained, and educational content can be available all the time, adapting the capacity-building schedule to the routine and language of individuals. Although internet access may be a limitation in some developing countries, where more traditional capacity-building approaches may be needed, connectivity has expanded exponentially, and many poor regions are already served by internet. People avidly consume social media by smartphones in their regular life and could easily access tutorial videos on restoration.

INNOVATION IN RESTORATION GOVERNANCE

In order to be successfully implemented in large spatial and temporal scales, restoration has to engage the multiple social actors operating in a given socio-ecological context (Guariguata & Brancalion, 2014). Thus, designing governance frameworks to promote innovative restoration, deal with trade-offs, and balance conflicting interests is essential. Environmental policies, in particular, may foster international competitiveness by inducing technological innovation when these regulations are well designed and lead to environmental improvement while business profits are not reduced (Porter & van der Linde, 1995; Ambec et al., 2013), a kind of "policy-push" trigger, as opposed to the previous "demand pull" trigger.

According to the "Porter hypothesis" (Porter & van der Linde, 1995; Ambec et al., 2013), environmental

Figure 5. Planning restoration legal compliance through a web-based registry system. Image of private farms (polygons surrounded by black lines) with their remaining native ecosystems (green polygons), production areas (gray polygons), and areas to be mandatorily restored (red polygons) according to the Native Vegetation Protection Law in Brazil, which substituted the Forest Code. Image source: DataGeo, Sistema Ambiental Paulista (<available at http://datageo.ambiente.sp.gov.br/app/indexMob.jsp?ctx=CAR#>, accessed on 18 October 2016). A web-based, self-declaratory system was established for registering farms and their areas of native vegetation protected and requiring restoration. Registration in this system is mandatory and is now a pre-requisite to obtain environmental licenses and agricultural credit. After only three years, 3.74 million farms, covering 387 million ha (97.3% of the total eligible area), were registered in this system, which has revolutionized the way restoration is spatially planned, enforced, and monitored in Brazil (Brancalion et al., 2016b). Since then, governments may use high-resolution satellite images updated periodically to check the status of each polygon where restoration projects are supposed to be implemented, thus improving the operationalization of compliance monitoring and the development of supportive policies to foster restoration in regions where legal commitments have not been fulfilled.

regulation "pushes" economic performance in a resource-efficiency and innovation-stimulating relationship, as this policy gives incentives to change production routines (technological or process innovation) in a way that leads to compliance and reduced costs through decreased resource inputs or increased efficiency. Nevertheless, these "policy-push" triggers must not forbid entrepreneurial freedom, punishing their failures if regulatory standards were not accomplished, like in the case of restoration activities in a compensation context. Innovative governance frameworks to support restoration have to consider this activity in the context of many other land use types coexisting in a given region (Latawiec et al., 2015) and consider their dynamics to change their internal decision processes to favor restoration and constrain degradation (Fig. 5).

INNOVATION IN LINKING RESTORATION SCIENCE, PRACTICE, COMMUNICATION, AND GOVERNANCE

Science, practice, capacity building, and governance innovations offer valuable opportunities to change the way restoration is perceived, planned, implemented, and monitored. However, it should also be acknowledged that these fields need to be integrated so that effective solutions address the totality of the problem, and not only its individual components separately. Integrating these fields is also an innovation endeavor that is crucial to advance restoration. In this sense, multi-stakeholder coalitions and networks may play an utmost role for integrating existing knowledge, technology, training approaches, and policy frameworks to ultimately change the paradigm of restoration in the 21st century. For example, the Atlantic Forest Restoration Pact (AFRP), a coalition with over 260 members from private companies, governments, NGOs, and research institutions in Brazil, has served as a multi-stakeholder, multidisciplinary platform to find common solutions for the most critical barriers for large-scale, effective restoration (Melo et al., 2013). Solutions have included the development of synthesis documents of restoration knowledge, a monitoring protocol, maps of priority areas for restoration for achieving different outcomes, and development of policies in partnership with national and state governments (Pinto et al., 2014).

Recommendations and the Way Forward

Restoration can greatly benefit from the use of an innovation approach to solve some of its most fundamental problems, but it may require relevant shifts to its modus operandi. One of the most-needed structural changes is regarding the way knowledge is generated and restoration professionals are trained. Potential use of knowledge to foster innovations has to be more actively explored and pursued. A post hoc approach, in which researchers naively believe that someone may use the knowledge produced independently of the efforts to link research and practice should clearly be avoided. We thus recommend that (1) research projects be developed in multidisciplinary teams, engaging potential end users (including practitioners, policy makers, program managers, and other researchers) from the conceptualization and continuing throughout development; (2) research projects consider innovation products as part of their expected results and outputs for funding agencies; and (3) academics foster an entrepreneurial behavior in their students, advising them not only to develop good projects and publish papers of excellence, but also establish startups.

The challenge for scaling up restoration to obtain its most expected outcomes will not be achieved by the simple sum of areas established by the restoration approaches of today, which have already been demonstrated to be insufficient to provide benefits perceived by stakeholders and ineffective to be implemented at larger spatial scales. Hopefully, a new generation of audacious students and professionals will find in ecological restoration a fertile ground to invest the best of their capacities and creativity to make a valuable contribution to heal the world, and the decades-old promise of restoration to provide a better future to people and nature will finally be fulfilled.

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