CONCEPTUAL FRAMEWORKS AND REFERENCES FOR LANDSCAPE-SCALE RESTORATION: REFLECTING BACK AND LOOKING FORWARD[1,2]

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Abstract

We review some of the most commonly known models in restoration ecology from the past 20 years. From these, we seek to identify essential elements required for the scaling-up and mainstreaming of restoration and, based on that, develop a new framework that could be used to assist in the realization of long-lasting and effective restoration policies and programs at the landscape and larger spatial scales. We argue that the reference model is particularly important at a time when there are urgent calls and investments for scaling-up restoration to the landscape scale. At that scale, we argue, it is essential to consider both ecological restoration and ecological rehabilitation as just two of the various components in a "family" of restorative activities that must be deployed, including changed management practices for agriculture, to make ongoing human activities and land uses more ecologically sound and sustainable. In conclusion, we present a new model that could help orient if not actually design planning, monitoring and evaluation, scaling-up, and applying restorative activities in new areas.

Key words: Historical continuity, holistic ecological restoration, landscape approach, reference system, restorative activities, restoring natural capital, scaling-up.

Scaling-up is one of the foremost challenges we face in the science, practice, and policy of ecological restoration today. To be successful and effective, scaling-up restoration will require conceptual tools with which to build robust projects and programs that convince stakeholders, decision-makers, and investors to get on board, and have a chance of producing adaptive, self-sustaining ecosystems.

Existing models and concepts in restoration ecology have merit, as discussed in detail below, but most are insufficient to the task of scaling-up in today's crowded world. Most of these models (e.g., Bradshaw, 1996; Hobbs & Norton, 1996; Whisenant, 1999) ignore *natural capital*, *ecosystem services*, and socio-economic issues that often matter more to many stakeholders than academic concepts like ecosystem functioning and biodiversity. For this reason, those models fall short of a holistic approach combining eco-centric and anthropocentric values. What's more, many of them blithely ignore history, as if people did not take the past—or should not worry about taking the past—into account when making decisions about future ecosystems and *landscapes* and limited resource management. Here, we focus on comparing models that do and do not address socio-economic concerns, and/or history (see also Higgs et al., 2014).

We shall begin by reviewing four conceptual models from the restoration ecology literature of the past 20 years that focus on flux and interactions of ecological attributes at the site or ecosystem levels, but fall short of holism for the reasons alluded to above. We also review one existing model that is relatively holistic and also incorporates historical reflection in ways the other four do not. Based on this review, we propose the notion of a *family of restorative activities* to be deployed conjointly at the landscape scale, especially in the case of mosaic landscapes where agricultural systems and other purely anthropocentric landscape units are in place and will almost certainly persist for the foreseeable future (Holl et al.,

[1] We dedicate this paper to Douglas Tompkins (1943–2015), conservationist and environmental philanthropist extraordinaire, who had an idea of the importance of ecological restoration and sought to apply conservation and restoration at large spatial scales.

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2003; IUCN & WRI, 2014). In other words, ecological restoration and *ecological rehabilitation* are just two of the various components in our proposed "family" of restorative activities, including changed management practices for agriculture, to make ongoing human activities and land use more ecologically sustainable. In conclusion, we present a new model that could help orient if not actually design planning, scaling-up, and applying this restorative "family" approach long term. (See Appendix 1 for definitions and discussion of key concepts and terms as used here. Each term included there is given in italics the first time it occurs in the main text.)

Recent Policy Advances

In the last five years, the mainstreaming and scaling-up of ecological restoration and rehabilitation have become widely recognized among enlightened decision-makers internationally as nothing less than imperative, and promising commitments to achieving them have been made by many governments in response to urgent calls for action from the UN (Reed et al., 2015). This welcome trend can be dated to 2012, when the Aichi Biodiversity Targets were ratified at the 11th Convention of the Parties (COP) of the UN Convention on Biological Diversity (CBD) (Aronson & Alexander, 2013), followed by decisions of the UN Convention on Combatting Desertification in October 2015, and the UN Framework Convention for Climate Change in December 2015. To date, over 80 countries have engaged resources and committed themselves to restore close to 30 million hectares of degraded land by 2020 (<http://www.wri.org/our-work/project/initiative-20x20/restoration-commitments#project-tabs>). This is an encouraging step toward a fundamental change of direction with regard to environmental management and the broad nature-culture relationship that drives it.

To make these global calls to action and national commitments meaningful, however, requires a science-based and socially endorsed framework of decision making in landscape planning and management. Only on that basis can we hope to achieve lasting synergy among conservation, sustainable use and management of resources, and restoration objectives. In this context, we emphasize that science (and scientific publications per se) are not fixed sources of truths, or very rarely so, but rather indications or reflections on the state and process of intellectual thought in a given field, at a given point in time. This intellectual thought-making and communication process is constantly in flux as well. Hence, there is a clear need to review the conceptual models and popular schematics in a field on a regular basis, especially in a young and rapidly evolving field like restoration ecology.

Taking this into account, we now review some of the most commonly known models in restoration ecology. From these, we seek to identify useful or essential elements required for the scaling-up and mainstreaming process, and, based on that, to develop a new framework that could be used to assist in the realization of long-lasting and effective restoration policies and programs. Notably, these include the *reference ecosystem* (or *reference model*) concept as it may be adapted to the landscape scale of intervention.

Background

To begin, we support the notion that to be effective and long lived (Reid et al., 2017), ecological restoration must be holistic (Clewell & Aronson, 2013). In other words, those who initiate restoration must aim not only to help impaired ecosystems recover lost complexity, functionality, structure, and "health," but also to increase their social, economic, and cultural desirability in the eyes of local residents and other stakeholders (see IUCN & WRI, 2014; McDonald et al., 2016a).

Thus, any conceptual framework or model for restoration that focuses exclusively on biophysical and ecological characteristics of a degraded ecosystem may be useful in one or more ecosystem types, as we discuss below, but remains only very partially applicable or transferable to the landscape scale.

To date, few holistic conceptual frameworks have been proposed for restoration that can, in our opinion, be directly applied at landscape and higher levels of complexity. The conceptual framework that is applicable in this regard is the one we call *restoring natural capital* (Aronson et al., 2007; cf. Cairns Jr., 1993). In this approach, ecological restoration and rehabilitation of degraded ecosystems are seen to be just two of several interlocking, restorative activities required wherever ecological *degradation* and *landscape fragmentation* have occurred at landscape and higher levels (de Groot et al., 2010; Blignaut et al., 2014, inter alia). Such an approach allows cooperation and coordination between ecology and economics in a fashion that we consider vital for the success of ecological restoration at higher spatial scales. It allows pursuing this activity in the spirit of Paul Hawken (Hawken et al., 1999), who first proposed the term "restorative economics" and its opposite "destructive economics" (although it is true that important precedents go back much further in the history of modern conservation, i.e., to the writings of George Perkins Marsh [1864], Aldo Leopold [Lin, 2014], and others). First, this approach is compatible with the notion of historically based reference systems and the idea that they can be applied at various spatial scales. Next, it is conceived and organized around the idea of participation and buy-in of as many stakeholders as needed within a specific context, whether or not they fully embrace the dual imperative of biological conservation on the one hand, and ecological restoration of degraded areas and ecosystems to recover ecosystem services on the other. *Reintroduction* of endangered species and *reinforcement* of threatened populations can and should also be included as needed. But, before reviewing the above-cited conceptual models and proposing a new model, specifically tailored for the landscape scale of perception and intervention, we shall devote a few lines to the reference ecosystem concept, which we consider fundamental to ecological restoration.

A key component of any conceptual model for ecological restoration, we have long argued, is the selection or construction of a relevant reference ecosystem (Aronson et al., 1993; Clewell & Aronson, 2013). While it is acknowledged that adjustments will be required, as described below, this is just as important at the landscape level as it is for ecosystem and site levels.

We note that Hobbs and Norton (1996) and others have expressed concern that the selection and definition of a reference ecosystem or model could be unrealistic or unnecessarily constraining. We counter that the reference ecosystem model does not define a rigid "goal" or an absolute target; rather it provides a beacon or pointer to a desirable future, and it dramatically helps in the vital process of consensus-building among stakeholders (Aronson et al., 2012; McDonald et al., 2016a). Furthermore, the use of history does not imply that we seek to walk backward into the future, so to speak, or grieve, or cling nostalgically to the past. In using a historically informed reference model we seek instead to keep in focus where we have come from, what has been lost, and what we seek to retain or recover. The concept of historical continuity (Clewell & Aronson, 2013) is the key here, not unachievable aims of historical fidelity.

Conceptual Models in the Restoration Ecology Literature: A Review

Ideally, conceptual models not only provide theories to test, but also provide information of direct use to planners, practitioners, and policymakers (King & Hobbs, 2006; Cowling et al., 2008; Balaguer et al., 2014). However, three of the most well-known conceptual models that have marked restoration ecology in the past two decades (Fig. 1A–C) are all inadequate, in and of themselves, to inform practice and policy for restorative activities undertaken at the landscape scale. They do, however, offer important insights and research horizons and help highlight some of the fundamental challenges to be addressed both from scientific and technological perspectives. In addition to these three, we shall also cite a recent model that combines elements of the first three, and further illustrates the value and limitations of these models (Fig. 1D).

The first model we consider was designed by A. D. Bradshaw, a modern pioneer of the restoration field, both as a scientist and as a practitioner. Bradshaw published and presented this seminal model in varying forms from 1984 to 1996. In Figure 1A we show one of several slightly different versions that exist in the literature (Bradshaw, 1996). This schematic has the merit of promoting focus on interactions of ecosystem structure and function, and in retrospect it has reinforced the foundational concept—that ecological restoration is one of the best platforms for the testing of ecological theory (Bradshaw, 1987; Harper, 1987). But, it also has problems from a practitioner's or stakeholder's perspective, such as the term "Original ecosystem" and the arrow going back to "Degraded ecosystem." In purely theoretical terms, the double arrows, bottom left to upper right, and vice versa, can be readily understood, but only by suspending the normal tendency to imagine trends and events as taking place in time, thereby with no coherent going back possible (see discussion of Fig. 1B, below). The science-practice gap is at the heart of the discussion here. While many conceptual graphs depict ecological processes without having time on the x-axis, including numerous models of ecosystem recovery following a disturbance (e.g., Hobbs & Suding, 2009), when it comes to application of these models in a practical setting, the problems far outweigh the benefits.

The rectangular box on the right side of Figure 1A labeled "Mitigation" is confusing from a contemporary perspective given that the role of *mitigation* in environmental laws and policy is still so variable and unsettled. Because of differing definitions and implementation, we suggest that the rectangle concerning mitigation is problematic and that the figure should only be reproduced if careful attention to the accompanying text is also provided.

Additionally, the representation on separate axes of "Ecosystem structure" and "Ecosystem function" is artificial and abstract. It has merit in some settings but not all, and it can easily lead to confusion and over-simplification if reproduced without adequate

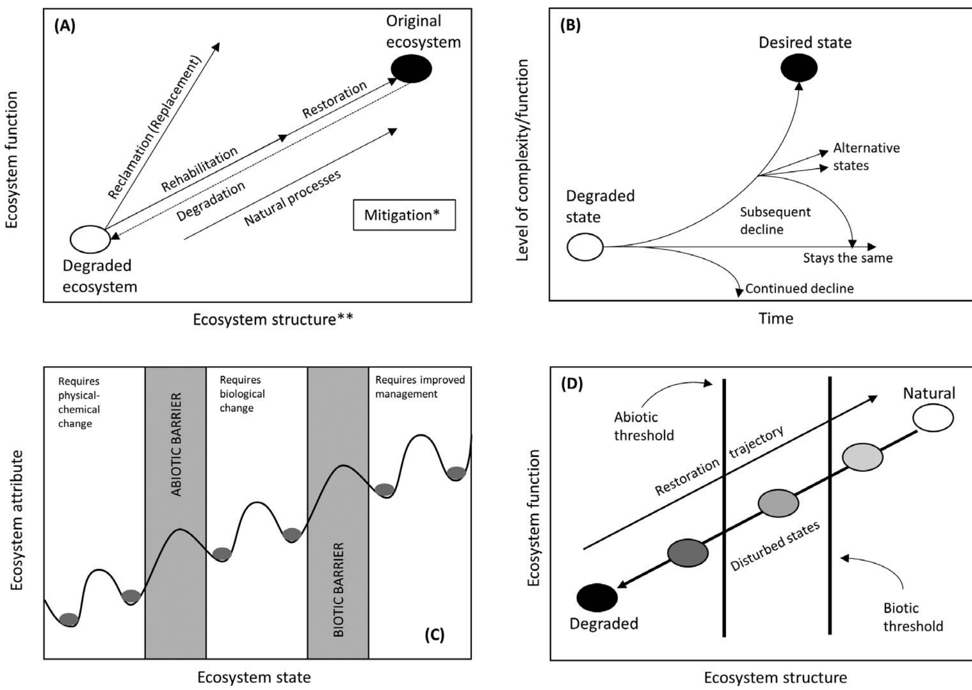

Figure 1. Four influential theoretical figures in restoration ecology. —A. Bradshaw's Ecological function × Ecological structure model. (modified from Bradshaw, 1996). *The complete text given by Bradshaw was: "Mitigation = Rehabilitation of another ecosystem." This is confusing and does not jibe well with the useful text he provides. **The full text in Bradshaw's model was "Ecosystem structure (species and complexity)," which is also confusing. See text for discussion. In the text of this very useful paper, Bradshaw also provides useful discussion of the terms Remediation, Replacement, Rehabilitation, and Restoration, but not Original ecosystem or Degradation, two terms that are also problematic unless carefully defined. —B. Bradshaw's 1996 figure revisited by Hobbs and Norton (1996); note that Time now occupies the x-axis, rather than Ecosystem structure (species and complexity), see Figure 1A. Problems persist, however, including the failure to consider history. See text for discussion. —C. The original two-barrier model of Whisenant (1999) that built on the drylands degradation model of Milton et al. (1994) and has been much reproduced and commented on subsequently. See text and Figure 1D. —D. New depiction of the "parallel degradation and restoration trajectories" (from Fig. 1A) in terms of functionality and structure (modified from Stanturf et al., 2014).

discussion. One very important and positive feature of Bradshaw's model is that he correctly highlighted the relationship between ecological rehabilitation and ecological restoration (see Appendix1).

In Figure 1B, we reproduce a revised version of Bradshaw's schematic, proposed by Hobbs and Norton (1996). For starters, just like Bradshaw's, this conceptual figure does not include history, whether from ecological or socio-economic and cultural perspectives. In contrast, Hobbs and Norton made a useful modification of Bradshaw's "function-structure" model by labeling the x-axis of their schematic figure "Time" instead of "Ecosystem structure," which makes the figure much easier to understand. The caption given to the y-axis, however, combines complexity and function, which is confusing to those without training in theoretical ecology, especially if one thinks of agri-systems where functioning, including primary productivity, is sought and partially achieved by *reducing* complexity. Furthermore, the "functions" or functioning referred to by ecologists should not be confused with functionality, in the same sense the term is used by economists. Economists and indeed most people considering ecological situations and processes focus on how and to what extent there is impact on people. In other words, from an anthropocentric perspective, ecosystem function is the "work" that ecosystems do for people through the generation of ecosystem services, which in turn, provide benefits to people that satisfy various values. In the past, when ecologists used the terms functions, functionality, and functioning with regard to ecosystems, they typically were not considering impact on people at all. A useful schematic we would recommend is one showing the relationship between ecosystems' underlying processes and their functions on the one hand, and human well-being on the other, with ecosystem services as the conceptual hinge between the two (see de Groot et al., 2010; Appendix 1).

In Hobbs and Norton's figure, shown in modified form in Figure 1B, the term "states," instead of "trajectory," is also problematic, given the fundamental insight that ecological restoration is a process, not a single isolated act or event. This may sound trivial, but in our experience, it is a fact that is often overlooked. It is more useful and accurate to say that our goal in ecological restoration is to help an ecosystem change its trajectory—away from degradation and instead toward recovery, repair, and self-regeneration—rather than its state (Clewell & Aronson, 2013). Indeed, it can be argued that given the flux of ecosystem states, it is only of limited value to discuss ecosystems at a given moment in time; instead, we should ideally always think about them as entities in continual flux (Botkin, 1990). The concept of phases can be useful as well, as discussed below.

Moving on, we shall now discuss the influential schematic offered by Whisenant (1999) (Fig. 1C). Building on earlier work by Milton et al. (1994), Whisenant described two putative barriers occurring along a conceptual gradient between "degraded" and "intact" ecosystem states. This model has been reproduced and tweaked repeatedly (e.g., by Hobbs & Harris, 2001; Sheley et al., 2009; McDonald et al., 2016a). Like Bradshaw's model, it has heuristic merit, but lacks an "anchor" in time or place. Further, the axes are labeled as "Ecosystem attribute" and "Ecosystem state," which in fact are the same thing. Simply put, a state is the total of all attributes. The diagram would make more sense if the x-axis were labeled "Time," as in Figure 1B, and if the y-axis showed an accumulation of attributes or a change in the value of a single attribute or suite thereof.

The model certainly has merit for directing attention to the identification of the causes of degradation as an important step in the restorative process, but it infers that abiotic and biotic "barriers" to restoration can always be disassociated; in reality, the distinction between abiotic and biotic barriers to restoration is rarely clear cut. This is a shortcoming similar to Bradshaw's artificial distinction between ecological function and structure discussed above in reference to Figure 1A. Notably, Hobbs and Harris (2001) revisited Whisenant's model and changed "barriers" to thresholds, or more precisely "transition thresholds." (Note: That figure is not reproduced here, for space considerations.) Arguably, this clarifies the direction in which the model should be read, but it also renders the figure more abstruse and theoretical. To wit, Whisenant's term "barriers" is quite concrete, whereas "transition thresholds" is an abstract and theoretical concept with no grounding in time.

Recently, Stanturf et al. (2014) made an important contribution (see Fig. 1D) by combining elements of the models of Bradshaw (1996), Hobbs and Norton (1996), and Whisenant (1999) to produce a schematic model to help restoration ecologists ponder how to tackle ecological problems in their respective biomes. These authors state that "the intermediate disturbed states (varying degrees of naturalness) are divided by abiotic and biotic thresholds that must be overcome to move to a new stable state" (Stanturf et al., 2014: S177). It is certainly true that this distinction between abiotic and biotic barriers or "thresholds" is useful for restoration ecologists. For example, an abiotic barrier is when planted trees cannot survive on land that has lost its topsoil. In contrast, a typical biotic barrier to restoration is when trees and shrubs are not dispersed to a restoration site because there are few native birds or mammals to disperse seeds and the nearest forest fragment is tens of kilometers away.

In a useful commentary on the schematic, Stanturf et al. (2014: S177) state that "For simplicity, these disturbed states are arrayed linearly but *in reality*, *the disturbed ecosystems may be located anywhere and the trajectories can be nonlinear* [italics added]." They also use "Natural" instead of "Original ecosystem" (Fig. 1A) or "Desired state" (Fig. 1B) and specify that "natural endpoint" is intended to represent "an idealized, pre-disturbance condition."

This language, however, may be counterproductive when divorced from the "Time" axis used in Figure 1B and which we suggested could have been usefully employed in Figure 1C.

Like Figure 1A–C, Stanturf et al.'s schematic overlooks the insight that can be provided by a historical review of the situation at hand, in any given restoration context, and does not provide tools for analysis, planning, and consensus-building such as are provided by the notion of a reference ecosystem (see below). In the world of practitioners, consulting and negotiating with stakeholders, financiers, legislators, etc., there are decision-making parameters to be taken into account related to planning, feasibility, availability of labor, resources, adequate governance, solid legal structures, land tenure systems, etc. (see van Dover et al., 2014; Reid et al., 2017). On the plus side, we welcome the authors' useful discussion of various contemporary uses and definitions of degradation (Stanturf et al., 2014: S164).

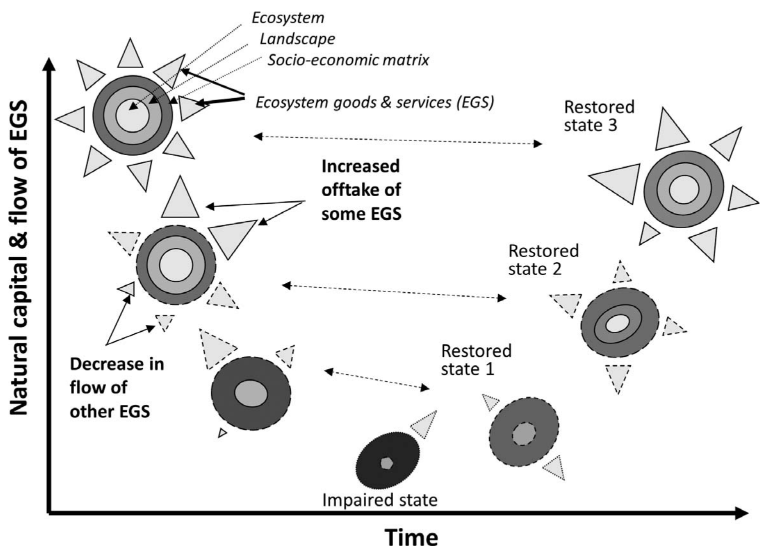

Figure 2. Generic multiple sequential reference model (Aronson et al., 2010; Clewell & Aronson 2013: fig. 7.5, p. 151; van Andel & Aronson, 2012: fig 1.4, p. 8). Note that concentric circles in each "star" represent an ecosystem within a Landscape and a Socio-economic matrix; triangular appendages represent *ecosystem goods and services* (EGS) that wax and wane in response to human behaviors. Each stage on the left of the model can be a potential framework for a landscape-scale reference, alone or in multiples, or sequential order, over decades or centuries during the restoration process. Dotted lines between a historic "star" and a "restored state" indicate one possible sequence of reference selections; others are also possible.

A Different Kind of Conceptual Model for Ecological Restoration

In Figure 2, we show a conceptual model that does look back as well as forward, in an attempt at a multi-scalar approach to restoration, and also considers societal as well as ecological factors, trade-offs, and outcomes (Aronson et al., 2010, 2012). The choice or construction of a reference ecosystem in this approach consists of identifying one or more natural or *semi-natural ecosystems*, which can serve as models for planning and executing an ecological restoration or rehabilitation project (Egan & Howell, 2001; SER, 2004; Clewell & Aronson, 2013). When no such site or valid ecosystem exists today, in the study area, we may assemble materials and construct a reference system from available information and knowledge about what did exist in the past, and what exists nearby today (White & Walker, 1997) within the limits of a "historical environmental variation" (Wiens et al., 2012; cf. Higgs, 2003). In addition, what we may call reference phases in a scenario or reconstruction of past *transformation* and degradation of an ecosystem can be used as reference models for successive phases of ecosystem recovery.

We invite readers to consider the study presented in Aronson et al. (2012) and analyzed in Woodworth (2013) for an example. Additionally, we reiterate that reference models may well include historical and geomorphological information, as well as the purely ecological (see Balaguer et al., 2014, for examples and further discussion of this idea).

Figure 2 illustrates schematically what happens when an ecosystem becomes overexploited or degraded in favor of one particular service, i.e., others "drop off" (left, top to bottom) and ecosystem health, integrity, and resilience decline. Indeed, one shortcoming of this model in the present context is that it only considers one ecosystem at a time and not an entire landscape, which by definition is an assemblage of interacting ecosystems (Forman & Godron, 1986). The "flow" of one or more ecosystem goods or services may increase over a certain period, but unless sustainability is built into the exploitation or extraction process and technology, the services provided by the ecosystem as a whole, and its fundamental durability, will inevitably decline. In economics such a process is described as "boom and bust."

The distortion and diminution of the circles representing an ecosystem within its biophysical and socio-economic matrices are further indication of damage and degradation, as well as landscape fragmentation. Unlike Figure 1A–D, Figure 2 incorporates socio-economic and cultural considerations, and it can be useful for thinking about scaling-up and integration in landscape-scale and regional programs. On the downside, it is complex and not as easily accessible as the previously cited models. It is also significantly more case-specific in essence, and it takes for granted the importance of reflecting back while looking forward, a posture that does not suit everyone and which cannot be presumed. Unfortunately, there are few examples that can be cited as yet where this approach has been fully adopted (but see Aronson et al., 2010; Balaguer et al., 2014); long-term field testing and validation are also lacking. Furthermore, Figure 2 ignores, or only implicitly accepts, that there is a wide range of restorative actions that can be applied to a range of land uses, and it ignores, or only vaguely implies, social choice. Choice is an essential consideration (see below). This is especially true at the landscape scale of complexity. The distortion and diminution of the circles representing an ecosystem within its biophysical and socio-economic matrices are further indication of damage and degradation, as well as landscape fragmentation (Hobbs & Saunders, 1993). An additional limitation of this conceptual diagram, as presented in Figure 2, is that it appears to assume that ecosystems historically provided a symmetrical, balanced portfolio of goods and services. Of course, this is not always true; hence the need for creating site- or landscape-specific models of this type for each new restoration project. What is presented in Figure 2 is merely a general model waiting to be applied, with modifications.

From Theory to Practice: New Tools to Help Meet the Challenges of Scaling-up

As discussed by Raven (2016) and several contributors to this special issue, the environmental problems we face today are immense (and interlinked with the other major problems we face as well). While there is a clear need for redoubled efforts, there is also cause for hope. To meet the objectives and the targets outlined by more than 80 governments of the world through the UN, EU, and IUCN, restoration has to take place, not only at large scale, but also in every individual habitat and ecosystem where degradation has taken place, from the sea bottom to alpine habitats and everything in between. This will require appropriate planning, adequate financing, coordinating, and consensus building (e.g., Nevill et al., 2016). One valuable, if preliminary, set of tools for these purposes, which is being developed, disseminated, and field tested by the IUCN, is the Restoration Opportunities Assessment Methodology (ROAM), for which a preliminary guide is available online (see IUCN & WRI, 2014). The SER International Standards document is also useful (McDonald et al., 2016a).

On a conceptual level, we note that there simply are no absolute ecological barriers to ecological restoration or rehabilitation, as portrayed in Figure 1C and D (see also Murcia et al., 2014); the barriers and obstacles are mainly social, economic, and psychological. This is worth emphasizing, given the fact that some ecologists (e.g., Hobbs et al., 2009) urge a thorough revamping of ecological restoration and conservation science on the basis of the premise that there are ecological barriers to restoration and, in the absence of any real evidence from the field, label ecosystems "hybrid" or "novel" (see Murcia et al., 2014, and Woodworth, 2017, for more discussion of this important point). We argue that the existing definitions of restoration ecology (see Appendix 1) are more valid than ever, but to promote serious scaling-up and mainstreaming, we need to add the notion of a "family" of restorative activities, along with that of restoring natural capital (Aronson et al., 2007) and ecosystem services (Cowling et al., 2007, 2008).

In brief, we argue that to accomplish a lasting scaling-up and integration of ecological restoration, it is worthwhile, in any given landscape deemed fragmented and degraded, to enunciate a "family" of restorative activities that can be conceived, planned, and carried out simultaneously or sequentially (Fig. 3; Appendix 1).

These inter-related activities within the "family" include and range from the most basic—*remediation* of polluted sites and *recuperation* of degraded lands and bodies of water for purposes of production or other utilitarian values—to the more challenging and ultimately more rewarding tasks of ecological and economic rehabilitation of natural or semi-natural ecosystems and full-scale ecological restoration of degraded ecological systems (sensu SER, 2004). As a unifying concept, pilots of the program can invoke the goal of making the supply and the value of the natural capital stock in the target landscape grow. Such increases are fundamental and a sine qua non for long-term economic and environmental sustainability and resilience, but it is rare that they are identified and sought after at a landscape scale. (Note: In the recently posted SER International Standards for ecological restoration document [McDonald et al., 2016a], the notion of a "restorative continuum" is proposed. Our concept differs in many ways and should not be conflated with that idea [see Appendix 1]).

A Conceptual Framework for Landscape-scale Restoration

Thus far, we have argued that many of the key models in the restoration ecology literature do not significantly contribute to the task of scaling-up

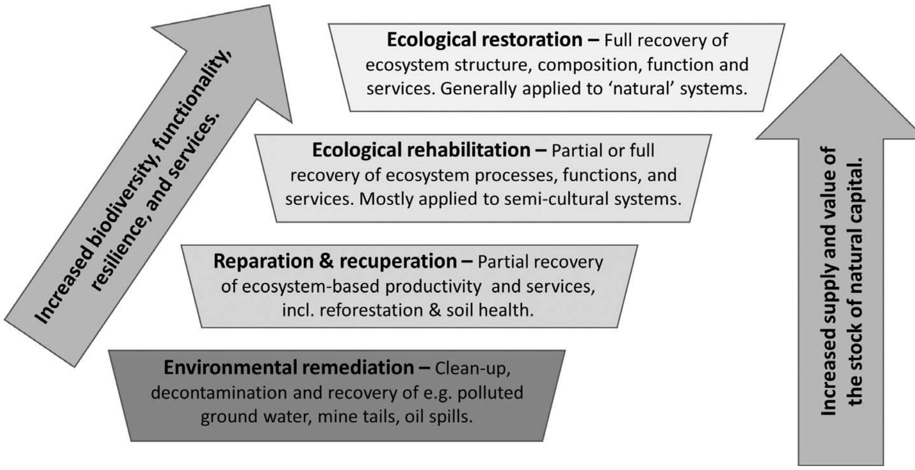

Figure 3. The "family" of restorative activities that can be practiced at a site or ecosystem level of complexity. The two "highest" activities follow definitions provided in SER (2004) and Clewell and Aronson (2013). To achieve lasting positive impacts on ecosystem services and natural capital, scaling-up to landscape and regional scales is necessary (Aronson et al., 2007; Reed et al., 2016). As one moves through—or better still, combines—the components of this "family" of restorative activities, biodiversity, functionality, resilience, and the services delivered to people generally increase. The timescale involved for each of these outcomes may of course vary, notably regarding ecological resilience. But for the sake of brevity we avoid adding further complication to the figure.

restoration to the landscape scale, with the exception of the restoring natural capital framework (as partially captured in Fig. 2). We have also proposed that selecting or constructing a historically based, or at least partially historically inspired, reference system for entire landscapes can be as useful a tool for guiding and orienting ecological restoration work at the landscape scale just as ecosystem references are useful, not to say essential, for the restoration and rehabilitation of individual ecosystems. Additionally, we have argued in favor of developing and deploying a "family" of restorative activities when addressing landscapes or larger and more complex areas (see Fig. 3). Given this complexity, it is conceivable that a landscape-scale reference model will often turn out to be built up as a bundle of ecosystem-level reference models, with special attention being paid to past, present, and desired future interactions among contiguous ecosystems. But that is beyond the scope of this paper.

Now what remains is to underline the fact that at the landscape scale, the selection of a reference system should be grounded in social processes that include multi-party stakeholders and subject specialists. Ensuring that this takes place may be more critical to achieving lasting results with landscape-scale restoration than improving existing science and technology (see also Holl, 2017; Reid et al., 2017).

In Figure 4, we offer a very simple chart related to restoration and reintegration at the landscape scale. It is intended to complement Figures 2 and 3. A triangle is used to denote a landscape such as a watershed consisting of three or four interacting ecosystems—woodland, river, estuary, etc.

Like Figure 2, but in a simpler fashion, Figure 4 depicts the process of degradation and imprudent use of resources, whereby a landscape becomes degraded and fragmented and then is considered for restoration. At some point, stakeholders, or society as a whole, must recognize that there is a problem of general concern and that a choice must be made in order to move ahead toward restoration. If no consensus is achieved on what to do differently, and instead a mindset of "business as usual" is allowed to prevail, the landscape in question is likely to become further degraded through an iterative process that we call a "spiral of degradation." If unsatisfied with that prospect, a society or community of stakeholders can choose to work toward the restoration of degraded ecosystems and revitalization of the fragmented landscape. This clearly requires a deep and lasting paradigm shift. However, it is at the landscape scale that many people most clearly identify a sense of place to which they "belong" (see Aronson & Le Floc'h, 1996; Higgs et al., 2014). Gaining consensus and motivation for a restoration and reintegration "enterprise" at the landscape or larger scales can, therefore, be facilitated by collectively addressing the following set of questions: (1) Who decides on the restoration objectives and targets to pursue? (2) Which decision-making process will be followed? (3) What are the desired outputs

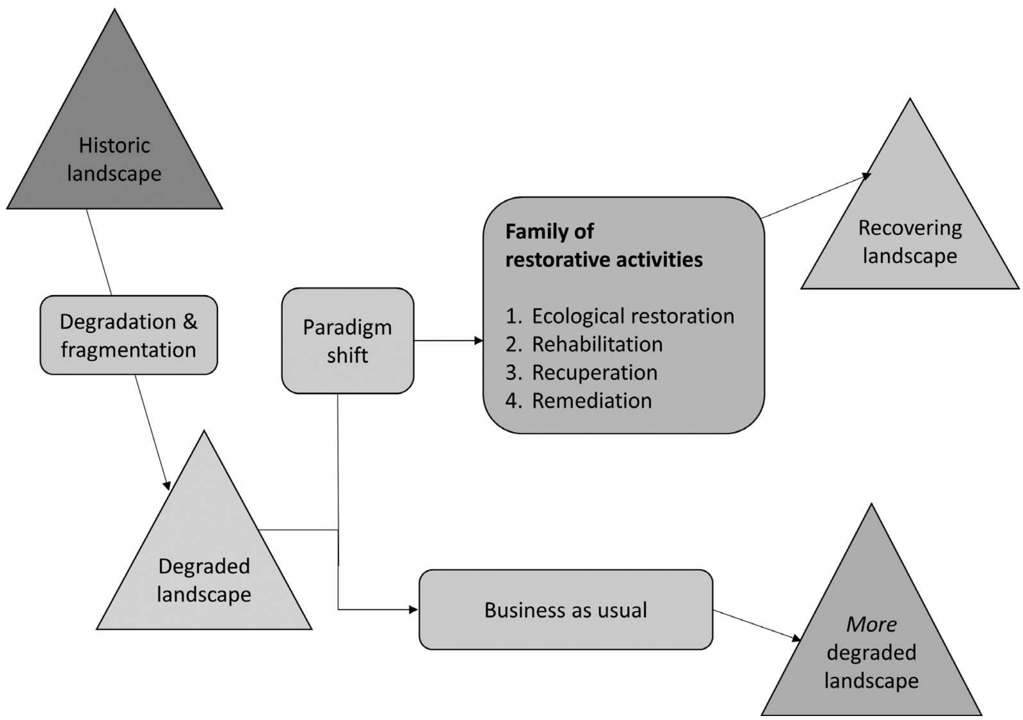

Figure 4. A landscape-level model of prolonged degradation and fragmentation showing two possible value-driven responses: abandonment or switch to a restoration culture and application of a "family" of restorative activities at various spatial and temporal scales (building on Aronson et al., 2007: chapter 1; Neßhöver et al., 2011, inter alia).

and outcomes of the restoration and reintegration process? (4) What are the success and longevity indicators to be used? (5) Which combination of restorative activities should be applied in the landscape, and where? (6) Who should pay for the restorative activities? (7) Who are the likely beneficiaries? (8) What are the likely losses to the value of natural capital, and to society, if *no* action is taken to halt degradation or, in other words, if no restorative activities are undertaken?

In our experience, the process of addressing and answering these difficult questions can be facilitated by collectively constructing a landscape-scale reference model, possibly with the aid of the schematic presented in Figure 2 (see also Aronson et al., 2010, 2012). This is time consuming and not necessarily straightforward, but we argue that it will aid stakeholders in their efforts to shift toward a restorative paradigm. The next step will be to outline the selection, financing, administration, deployment, and monitoring of the appropriate "family" of restorative activities for a given landscape (or, in theory, for an entire region or country). However, to truly help rehabilitate and restore degraded ecosystems and reintegrate fragmented landscapes will almost certainly require an ethical as well as ecological and economic consideration and commitment.

Conclusion: Looking Forward

We began by reviewing several existing conceptual models for thinking through and implementing ecological restoration. While the models considered all have their merits, reflecting back on them does reveal shortcomings. Four of these are: (1) They tend to focus narrowly on restoration actions outside of economically productive landscapes containing anthropocentric activities like mines and agricultural fields, cities, and roadways. (2) The models discussed generally represent restoration in general and the implied decision to restore as well as the hoped-for restoration process in some ecological detail. However, they fail to consider social and stakeholder involvement and inevitable trade-offs that will arise. (3) The models, by and large, do not include the need for looking back in order to move forward; in other words, the need for making historically informed decision-making to assist in the development of a desired reference system to guide the collective enterprise. (4) The aforementioned decision-making (see item 3) requires a paradigm shift whereby decision-makers acknowledge the ills and the consequences of decisions taken in the past, as well as the historic and current development trajectory of an individual ecosystem or landscape, and then initiate transitions toward a restorative pathway. This will require investment and negotiation, but will ultimately enhance both the quality and the quantity of ecosystem services and thereby contribute much toward advancing sustainability and social justice. Even if absent from a schematic model itself, the text presented with regards to any restoration model should include discussion of this sine qua non for scaling-up restoration to larger spatial and temporal scales.

Mindful of the shortcomings and gaps just listed, we then offered a conceptual framework that could be considered by those working to scale up ecological restoration and related activities to the landscape scale, as well as national and regional scales. To go one step further, we argue that at the scale of our biosphere, restorative activities are our last resort if we wish to work toward a sustainable and desirable future. Happily, there are positive signs in this direction, but a great deal more work must still be done.

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APPENDIX 1. Key definitions as used in this article. Sources (unless otherwise specified) are van Andel and Aronson (2012).

Degradation: The simplification and loss of biodiversity in an ecosystem caused by anthropogenic or non-anthropogenic drivers of disturbance. In cases of severe and prolonged ecosystem disturbance, natural ecosystem recovery (alias *spontaneous regeneration*) is sometimes no longer possible in a relevant or "reasonable" period of time, or only proceeds in a limited fashion, i.e., with limited recovery of native biodiversity. Degradation, resulting from various factors, including both human and non-human, generally reduces flows of ecosystem goods and services.

Ecological rehabilitation: The improvement of functionality of an ecosystem, either in a natural or semi-natural landscape setting, or a managed production system, without necessarily achieving a return to "pre-disturbance" conditions. Emphasis is generally on restoring ecosystem processes and functions so as to increase the flow of services and benefits to people (SER, 2004; Clewell & Aronson, 2013). Care must be paid not to heavily favor one function with the result of rendering the ecosystem more fragile or vulnerable than it was before.

Ecological restoration: "The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER, 2004; Clewell & Aronson, 2013). Unlike ecological rehabilitation, wherein recovering functionality is given priority, here ecosystem structure, composition, and functionality are equally prioritized (cf. Aronson et al., 1993). The core idea is that here we actively attempt to jumpstart and perhaps guide the recovery and return to an ecosystem trajectory within a historical range of variation (Wiens et al., 2012; Balaguer et al., 2014). See also *Restoring natural capital*.

Ecosystem goods and services (EGS) (or ecosystem services [ES]): "The direct and indirect contributions of ecosystems to human wellbeing" (de Groot et al., 2010). EGS are made possible thanks to ecosystem functions and the still deeper ecosystem processes and structure. The Millennium Ecosystem Assessment (MEA, 2005) recognized four categories of ES, namely, supporting, regulating, provisioning, and cultural.

Family of restorative activities: Includes remediation of polluted sites, reparation and recuperation of degraded lands and bodies of water for various purposes, ecological and economic rehabilitation of natural or semi-natural ecosystems, and full-scale ecological restoration of degraded ecological systems. In contrast to the Standards for Ecological Restoration in Australia document (McDonald et al., 2016b), we leave mitigation out of the "family" depicted here for reasons explained in the text.

Landscape: Many acceptable definitions exist for this concept. Here, we use the ecological definition, namely an assemblage of ecosystems that are arranged in recognizable patterns and that exchange organisms and materials such as nutrients and water (see Higgs et al., 2014). Today, most landscapes are mosaics of interacting systems that may be natural or cultural, or some combination thereof and, therefore, labeled semi-natural (or semi-cultural). These typically include production systems and other systems managed by people for social and economic use, e.g., transportation, water supply, etc.

Landscape fragmentation: The separation of a formerly continuous natural area into smaller natural units that are isolated from each other by lands that were converted for economic production or the development of infrastructure such as road building. The concept of reintegration (Hobbs & Saunders, 1993) can be applied to efforts to rehabilitate and revitalize whole landscapes that have become fragmented, both ecologically and socio-economically (Aronson & Le Floc'h, 1996b). Increasingly, it is recognized that to be truly effective, both ecosystem restoration and restoring natural capital should be planned and managed with a landscape approach where a system is degraded (e.g., Crossman & Bryan, 2009).

Mitigation: To mitigate is "to appease... or to moderate the heinousness of something. So although mitigation can be an outcome of restoration it is a separate consideration" (Bradshaw, 1996: 3). Ecological restoration can be a method to achieve mitigation (or, rather, offsets or compensation), but there is a difference in logical type between these concepts, and they should not be confused or conflated.

Natural capital: A metaphor borrowed from economics to denote the limited stocks of physical and biological natural elements found on Earth, some of which are of direct use to human society (then called resources) and others which are not (de Groot et al., 2010).

Reference ecosystem (or reference model): One or more natural or semi-natural ecosystems, ecological descriptions thereof, or, if these are unavailable, assemblages of characteristics of presumed natural or historic semi-natural ecosystems, which are chosen to serve as guides, reminders, benchmarks (though not to be confused with "baselines"), or targets for planning in ecological restoration and rehabilitation projects (White & Walker, 1997; Egan & Howell, 2001; SER, 2004). There can be multiple references used (Suganuma & Durigan, 2015) or sequential references selected or assembled for a given restoration project (Aronson et al., 2010).

Reinforcement: The process of strengthening a small and vulnerable population of a plant or animal species in situ. See also *Reintroduction*.

Reintroduction: The intentional introduction of a plant or animal species in a site or ecosystem from which it has been extirpated or in areas where it is considered threatened or vulnerable. See also *Reinforcement*.

Remediation: The cleaning up of polluted sites, such as post-mining areas or oil spills, etc., and removing the risk of contaminants or toxic chemicals that may affect other ecosystems and landscapes. This can be a standalone operation or the first step in an ecological restoration or rehabilitation project or program. Note that Bradshaw (1996: 3) proposed: "Remediation is the act of remedying. To remedy is 'to rectify, to make good.' Here the emphasis is on the process rather than on the endpoint reached."

Recuperation: The recovery, through any and all means, of degraded lands, abandoned sites, etc., including regenerative agriculture, etc. The goal to bring the site, land, or ecosystem back to a productive condition wherein sustainable use is once again possible.

Restoring natural capital: Consists of four elements (Aronson et al., 2007): (1) ecological restoration of degraded natural and cultural ecosystems (sensu SER, 2004); (2) making production systems (e.g., agriculture) more ecologically sound; (3) making resource extraction, energy, and transport sectors' work more ecologically sound; and (4) education and communication to increase awareness of the importance of natural capital and ecosystem services in our everyday lives. Of the four types of natural capital recognized by the MEA (2005), "renewable" (i.e., natural and semi-cultural ecosystems and their native biodiversity) and "cultivated" (i.e., traditional crop varieties and races of livestock, and traditional agro-ecological knowledge) are most relevant here (Neßhöver et al., 2011).

Semi-natural ecosystems: A landscape that has developed under the joint influence of natural processes and human organization and resource use. Typically juxtaposed with highly managed production systems and fully natural systems in a self-renewing or shifting mosaic. Sometimes called semi-cultural.

Spontaneous regeneration: As stated in the SER Primer, the ultimate goal of ecological restoration is to promote and assist spontaneous regeneration or recovery of damaged ecosystems through active interventions. When no interventions are taken or needed to achieve restoration or rehabilitation, the result can be termed "spontaneous" or "natural" regrowth (Chazdon, 2014, 2017; Chazdon & Guariguata, 2016).

Transformation: A value-neutral term describing a reallocation of a site or ecosystem for anthropocentric needs or desires. Useful in discussions of landscape-scale planning and management.