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Possibilities and limitations of passive restoration of heavily disturbed sites

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ABSTRACT
Passive restoration, which relies exclusively on natural processes and technical reclamation, which intervenes strongly into the restoration process, represent the extremes of a restoration action continuum. Between the extremes, we consider various degrees of active restoration. We suggest a general scheme to determine which approach to use based on site conditions, landscape context and societal circumstances. We conclude that passive restoration should usually be preferred in smaller sites with low abiotic stress and moderate productivity that are recovering from moderate disturbances. A passive approach may also be preferred in those landscapes that are less altered by humans, where target species are common and both invasive aliens and strong competitive generalists are rare. In such landscapes, passive restoration may succeed even if initial disturbances are intense. Potential of passive restoration has not yet been fully utilised. Passive restoration is viable economically and can produce multiple social and ecological benefits.

KEYWORDS
Alien species; disturbance; landscape context; restoration; target species

Introduction

Restoration of damaged sites commonly involves active interventions to initiate, accelerate, or direct recovery of a damaged ecosystem towards a stage that is structurally and functionally similar to that which previously occurred (van Andel & Aronson, 2012). However, restoration ecologists continue to debate whether damaged ecosystems can recover spontaneously in a reasonable time without external supplementary intervention (Bradshaw, 2002; Clewell & McDonald, 2009; Hobbs & Cramer, 2008; Holl & Aide, 2011; Prach et al., 2001; Prach & del Moral, 2015; Prach & Hobbs, 2008; Rey Benayas, Bullock, & Newton, 2008; Zahawi, Reid, & Holl, 2014). Such passive (*sensu* DellaSala et al., 2003) or spontaneous restoration depends solely on natural processes such as colonisation and regeneration to produce a desired result, that is, to approach a restoration target. The restoration target may not be like the surrounding landscape and potential natural vegetation may not always be the target (Siles, Alcántara, Rey, & Bastida, 2010). Rather, goals that prioritise nature conservation, habitat protection, biodiversity enhancement, recreation, public safety or aesthetic values may even demand targets that differ from natural or semi-natural vegetation. Further, spontaneous development may require more time to develop adequately. Once desirable targets are characterised, local conditions should be assessed to determine which restoration approach would be more successful. In this paper, we seek generalisations that would assist making this determination.

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Passive restoration forms one end of a continuum of restoration activities (Holl & Aide, 2011; Prach & Hobbs, 2008) and is in unambiguous contrast to technical reclamation approaches at the other extreme of this continuum. Technical strategies are normally applied to heavily disturbed sites (Whisenant, 1999). They include recontouring landforms, importing topsoil and planting or sowing all or most target species. Moderate interventions have been called active restoration and include an enhancement of abiotic site conditions (e.g. fertilisation), the suppression of undesirable species (e.g. strong potential competitors or invasive species), planting or sowing target species early in the process (Bradshaw, 1987) and creating internal heterogeneity. Spontaneous processes may also provide enhancement of these active tactics. Though some authors consider the term reclamation to be redundant (Clewell & Aronson, 2013) and recommend using restoration for all such actions, we consider reclamation to be a useful subordinate term which describes activities that rely solely on technical measures which can be emphasised using the word technical. The essential question is whether passive restoration can produce desired targets efficiently, that is, within an acceptable time fame and at low cost. To answer this question requires knowing those factors that could limit effective passive restoration and the environmental conditions that support passive restoration. We combined lessons from the literature (especially Holl & Aide, 2011; Prach & Hobbs, 2008; Walker, Hölzel, Marrs, del Moral, & Prach, 2014) with our experiences to explore the conditions that would suggest that the use of passive restoration would be successful. We enlarged the previous attempts to generalise by considering more factors and variation in their intensity in determining success and by integrating them with an emerging new conceptual scheme that can be generally applied. We concentrated on how abiotic stress, site productivity, disturbance intensity, character of the landscape surrounding a restored site and societal circumstances affect this determination.

What conditions support a preference for passive restoration?

We considered four groups of determinants that affect the success of passive restoration: (a) abiotic site conditions; (b) intensity, extent and type of the initial disturbance; (c) biotic interactions, such as, competition and grazing; and (d) the landscape matrix, such as, presence of target species, invasive aliens and dispersal vectors. Biotic interactions depend explicitly on those species present and normally change during ecosystem development. For example, intensive competition from first colonisers may impede the establishment of both target and undesirable species (Gentili, Montagnani, Gilardilli, Guarino, & Citterio, 2017; Titus & Bishop, 2014) in accordance with the inhibition model of Connell and Slatyer (1977). Therefore, *a priori* determination of one approach over the other based on biotic interactions is problematic. Due to this high degree of specificity and variation based on multiple contextual parameters, we cannot make generalisations that predict how biotic interactions may affect success of any restoration project. Instead, we focus on the remaining groups of determinants of restoration success. The degree of projected success must be a major factor in determining if passive restoration should be prescribed in restoration projects.

We suggest six generalisations that relate to the probability of success (and hence degree of preference) using six variables (Figure 1). In each graph, P = passive restoration and R = technical reclamation. Preferences for one or the other approach are likely to change along the gradients depicted, and intermediate cases might suggest that targeted active restoration of various intensities might be appropriate. In these graphs, passive curves may include minor interventions to initiate or modify spontaneous development. We are aware that in the real world, several or even all the considered factors act together and their separate depiction in Figure 1 is for clarity. Their effects on the success of restoration can be synergistic or compensatory, although considering all the factors individually may provide useful guidelines to prescribe a particular restoration approach. We stress that the lines in the figures are plotted only for heuristic purposes and are qualitative, not quantitative.

Relevant abiotic factors can be summarised by a stress-productivity gradient (Grime & Pierce, 2012). Here, we consider stress (Figure 1(a)) and productivity (Figure 1(b)), often determined by the degree of stress, separately. For example, a high degree of stress may be imposed by extreme

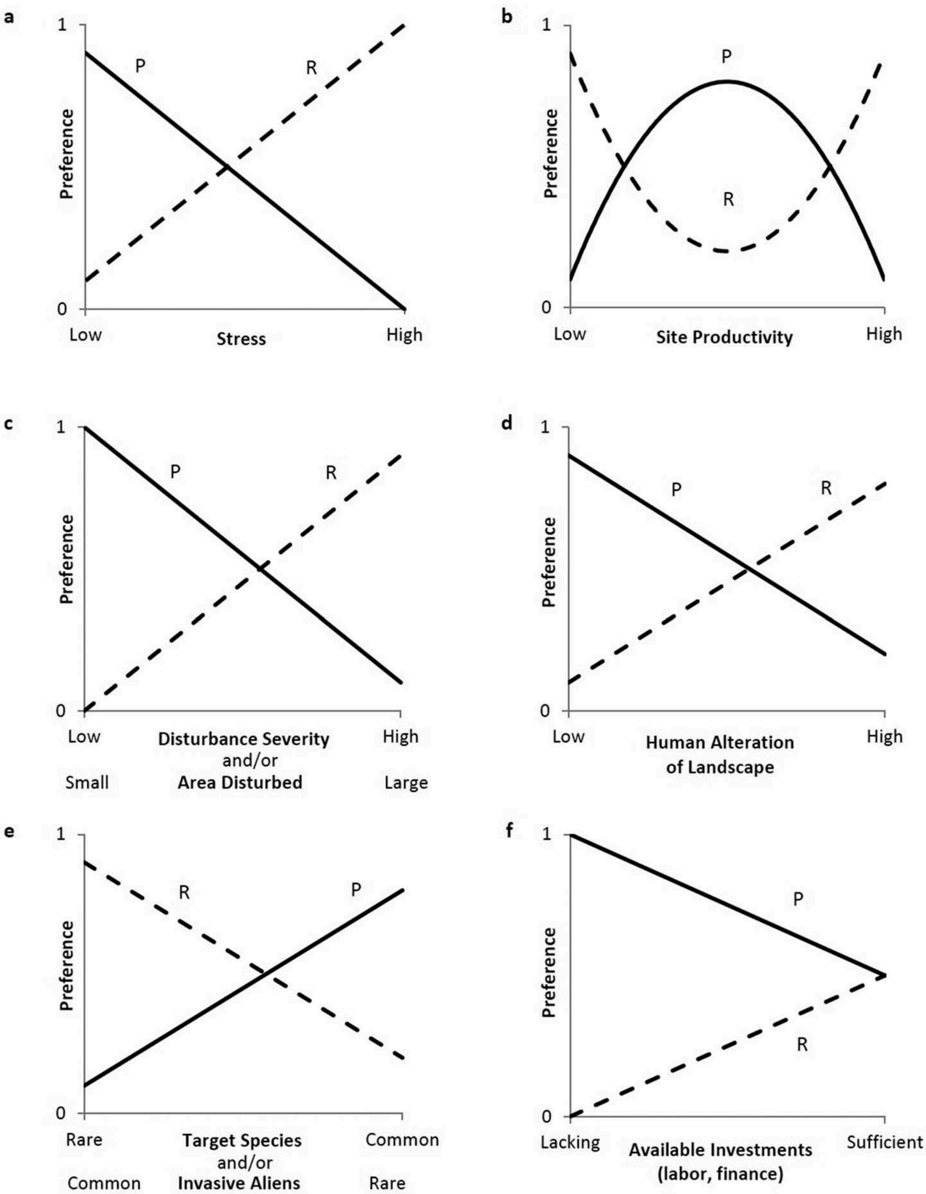

Figure 1. Preference of passive restoration (P) as a consequence of its probability success and its consequent preference in comparison with technical reclamation (R) along changing environmental conditions.

Technical reclamation is considered here as the extreme active approach, while the combination of P and R corresponds to moderate interventions, i.e. active restoration. Combinations of all the environmental factors should be considered in one restoration project to optimise the restoration activities.

values of soil pH that are unlikely to allow passive recovery (Skousen, Johnson, & Garbutt, 1994). Similarly extremely low soil fertility (Mentis, 2006) or toxic levels of heavy metals (Bagatto & Shorthouse, 1999) prevent passive recovery. Extremely wet or extremely dry sites both also impose stress (Ninot, Herrero, Ferré, & Guàrdia, 2001) that are likely to require technical reclamation (Brofas & Varelides, 2000). Stressful sites often require appropriate amelioration to improve biodiversity, ecosystem functioning or both (Whisenant, 1999). However, some smaller extreme sites may develop some natural value and be left without assistance.

The preference for passive restoration along a gradient of site productivity follows a unimodal response curve (Figure 1(b)). Passive restoration will likely fail under extremely low productivity due to restricted establishment and slow growth (Mentis, 2006) and at high productivity, where a few competitive species will preclude further establishment and arrest successional development (e.g. del Moral & Magnusson, 2014). Technical measures are needed to promote fully developed vegetation in extremely unproductive sites, often by improving fertility and in highly productive sites, by managing competition. Strong dominance typical of highly productive sites diminishes species diversity and alters ecosystem functioning such that desired target species may not become established (Smith & Olff, 1998). Highly productive sites are often prone to invasions by aliens (Luken, 1997; Paschke, Redente, & Brown, 2003; see Figure 1(e)). Technical measures, such as topsoil removal, repeated harvesting, or nutrient immobilisation, are required to release the system from stagnation (Walker & del Moral, 2009). It is in the middle of the productivity gradient that we expect passive restoration to be the more successful (Prach & Hobbs, 2008; Walker et al., 2014) because conditions foster establishment but limit competitive suppression (del Moral, 1983).

The choice between passive restoration and technical reclamation also depends both on disturbance intensity and size of a disturbed site (Figure 1(c)). If the disturbance severity is low, there will be many survivors and recovery will be rapid. If the area is small, dispersal limitations will be minor even after a severe disturbance (Dovčiak, Frelich, & Reich, 2005). In either case, passive restoration should be rapid and successful and we can depend on it. Large (i.e. hundreds of hectares) sites intensely disturbed by humans, such as spoil heaps from open-cast coal mining, will usually require at least some active restoration or even reclamation at least on a part of the area (Baasch, Kirmer, & Tischew, 2012). Note that some patches could be excluded from treatment to allow passive restoration that would enhance biodiversity (Kirmer et al., 2008; Prach, Řehounková, Řehounek, & Konvalinková, 2011).

The degree to which humans have altered the landscape affects the potential for immigration by suitable species (Figure 1(d)). In less altered and traditionally managed landscapes, passive restoration usually proceeds towards valuable ecosystems (Ruprecht, 2006). In strongly altered, uniform landscapes (e.g. arable lands lacking corridors or remnant semi-natural vegetation), passive restoration cannot be expected to produce a desirable result (Boccanelli, Pire, & Lewis, 2010). Such landscapes are often dominated by invasive alien species and target species are lacking (Hobbs, Higgs, & Harris, 2009). Active restoration measures are required to suppress undesirable species and support target species (Figure 1(e)). However, biodiversity in extreme sites (Figure 1(d–e)) may be enhanced if some portions are left to passive restoration even if invasive species are present. For example, invasive alien species have been reported to act as nursery plants facilitating establishment of target species, allowing passive restoration to be successful (Becerra & Montenegro, 2013).

Planning optimal measures in restoration programmes must consider both ecological and economical factors (Walker et al., 2014). Passive restoration costs are naturally substantially lower than those of active restoration (but see Zahawi et al., 2014). If financial or labour investments are unavailable, there is no option other than to prescribe passive restoration (Figure 1(f)). If sufficient financial resources are available, we must balance ecological, economical, and societal aspects of a project, in particular the rates at which each may reach a target. It may be that limited or no intervention will produce substantial benefits, while further expenditures will yield diminishing returns, but it can also be the opposite. If passive restoration is preferred, any available funds could be reserved for subsequent interventions should monitoring reveal developing problems (e.g. increasing competitive dominance or invasion of exotics). Due to many alternatives, we put equal preference either for passive restoration or technical reclamation if sufficient resources are available (Figure 1(f)) or active restoration representing the continuum between the two approaches can be applied.

Passive restoration in context of restoration activities

These general patterns (Figure 1) only provide a conceptual, heuristic framework to restoration projects; they are not strict guidelines to restoration of any particular site. They should be always combined with consideration of site-specific circumstances and restoration goals (del Moral, Walker, & Bakker, 2007) taking into account all the factors plotted at the first axis in the figures. There is a range of situations from those that only require time for complete restoration to those needing intense reclamation. Passive restoration is most successful in small, mildly disturbed sites with moderate productivity that are under low abiotic stress in a more natural landscape. This generality emerges by combining the aspects of Figure 1. Technical reclamation should be preferred in the opposite mixture of the factors. It is especially urgent, for example, in the case of toxic substrates where there is a danger of contamination (Feigl, Gruiz, & Anton, 2010). Similarly, sites subject to erosion that threaten the surroundings must be reclaimed technically (Albaladejo Montoro, Alvarez Rogel, Querejeta, Díaz, & Castillo, 2000). Technical measures are also justified if we need productive sites rapidly, for example, for fodder or timber. On the other hand, if we wish to improve natural values of a site, passive or moderately active restoration or mosaic application of different approaches can be recommended to provide a diverse and valuable environment. Moreover, as any major restoration project requires monitoring (Walker & del Moral, 2003), initial decisions may be revisited and interventions may be modified or introduced subsequently. Delayed intervention, working with passively developed sites may be more economical than immediate total reclamation. In addition, ongoing human-interventions into passively recovering sites may substantially support biodiversity (Řehounková et al., 2016). Intermediate interventions are common in restoration programmes, but the minimum intervention strategy or the minimum treatment required (Bradshaw, 2002) should be carefully considered.

Despite substantial knowledge of the effectiveness of passive restoration, its potential to be used in restoration projects remains undervalued (Prach & Pyšek, 2001). On the other hand, many ecosystems must recover spontaneously because they are beyond the bounds of formal management. For example, abandoned grazing lands often recover spontaneously (Cramer & Hobbs, 2007; Wilson, 1994). However, passive, or spontaneous, restoration may produce vegetation with reduced structural complexity or diversity compared to actively restored landscapes (Brancalion et al., 2016; Cava, Pilon, Ribeiro, & Durigan, 2018). Societal acceptance and limited ecological understanding among decision-makers can produce legislation that favours technical measures. Technical reclamation can deliver basic benefits (Roa-Fuentes, Martínez-Garza, Etchevers, & Campo, 2015) and may be favoured because of an enduring technocratic philosophy and easier predictability. The products of passive restoration are less predictable, more stochastic and subject to unanticipated problems (Suding, Gross, & Houseman, 2004), although similar uncertainty often results in active restoration (Shoo, Scarth, Schmidt, & Wilson, 2013). Zahawi et al. (2014) showed that local human populations might consider passively restored sites to be untidy, useless abandoned land and wonder why active restoration has not been implemented to hasten a return of productive land. Even if landscape constraints preclude the unaided community development comparable to the original vegetation, passive restoration can produce structures that provide comparable ecosystem and habitat values (Morrison & Lindell, 2011).

Conclusions

Passive restoration often yields improved biodiversity and greater ecological function in degraded ecosystems at the expense of slower recovery and less predictable ecosystem properties. Passive restoration that produces a variety of tangible benefits requires substantially lower costs than technical reclamation, which may offset the costs of slow development. Partial, directed intervention into spontaneous processes, that is, active restoration, may produce a more desirable result with limited costs. In most cases, restoration ecologists should explore mixed strategies to produce acceptable results with reduced costs.

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