

Landscape Ecology Perspective in Restoration Projects for Biodiversity Conservation: a Review

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Abstract

There is good evidence that the results of a restoration program depend largely on the landscape context such as habitat cover, connectivity and isolation. Such evidence, however, is not coherently presented in the scientific literature. This review aims to provide an overview of how landscape ecology has been used in restoration projects in the last 15 years. We found only 54 empirical restoration studies published in international journals from 1997 to 2011 that used a landscape approach, mostly published between 2009 and 2011. The majority of the studies were carried out in temperate zones and forests, with habitat loss and fragmentation as the major disturbance factor (77%). Biotic manipulation was the most common management protocol (39%), followed by abiotic manipulation, land abandonment, and control of disturbance sources. Most of the studies (84%) demonstrate that the landscape context plays an important role in restoration processes. Particularly, a positive influence of the landscape context on restoration effectiveness was observed for restored areas in close proximity to neighboring patches and in landscapes with high habitat cover. However, we found that the effect of landscape characteristics on restoration outcomes may vary with species characteristics, and differ according to the population or community parameters (e.g. abundance, richness, composition) considered. In addition, different landscape aspects mediated the effects of restoration on biological communities, and thus there is not a unique set of landscape indices that can be universally used for restoration planning and monitoring. Although the literature has important gaps, since most studies are restricted to few habitat and disturbance types and consider only a limited set of landscape attributes, our findings demonstrate that landscape characteristics can be as important as local factors in influencing restoration outcomes and should be incorporated in restoration projects and programmes. By considering a wide range of landscape resilience and disturbance condition since the beginning of future restoration plans, we expect that the main gaps of knowledge identified here can be filled in the near future, helping then to reveal a more general pattern relating landscape structure to restoration outcomes.

Key words: Landscape Resilience, Landscape Structure, Restoration Strategies, Disturbance.

Introduction

The mutualistic links between landscape ecology and restoration ecology became solid in the mid 1990s (Naveh 1994; Hobbs & Norton 1996; Aronson & Le Floch 1996; Bell *et al.* 1997). Those authors suggested that the success of a restoration action depends on the landscape context, as the processes that create and maintain restored areas are influenced by ecological and cultural dynamics at larger, landscape-level scales (Naveh 1994). Further, restoration actions can provide unique opportunities to test the effects of spatial patterns on ecological processes at larger scales (Bell *et al.* 1997), which is the main objective of landscape ecology (Turner 1989).

Along with the growing association between restoration ecology and landscape ecology came the recognition that factors that impede restoration success, previously known to exist at local scales (Suding *et al.* 2004; Briske *et al.* 2008), are also operating at larger scales (Holl & Aide 2011). When focusing on biodiversity conservation, these large-scale restoration constraints may be related to low habitat cover and connectivity and a high degree of isolation of the restored area, which has been shown to affect the system resilience and the restoration outputs (Holl & Aide 2011). This represents a shift in the view of local site-by-site restoration action to a larger and multiple scale perspective (Naveh 1994; Hobbs & Norton 1996; Bell *et al.* 1997).

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The fact that landscape characteristics can affect ecological processes and species distributions, especially in fragmented landscapes (Metzger *et al.* 2009; Banks-Leite *et al.* 2011; Martensen *et al.* 2012), is also relevant for restoration

actions focused on biodiversity conservation. It particularly happens when we consider spatial attributes that regulate landscape connectivity (the capacity of landscapes to facilitate biological fluxes, such as animal movements, and pollen and seed dispersal; Taylor *et al.* 1993). Landscape characteristics as habitat isolation, the presence of corridors and matrix permeability are known to affect landscape connectivity (Boscolo *et al.* 2008; Martensen *et al.* 2008; Uezu *et al.* 2008), which can influence (re)colonization dynamics (Jacquelyn *et al.* 2003), and thus restoration effectiveness (Rodrigues *et al.* 2009).

Recent studies suggest that landscape structure, essentially landscape cover and connectivity, can be related to landscape resilience (the capacity of landscapes to recover from local species losses through immigration at larger spatial scales; Tambosi *et al.* 2014) and management effectiveness (Tschardt *et al.* 2005; Pardini *et al.* 2010). These authors suggest that the best cost/benefit ratios of a restoration action for biodiversity conservation occur in landscapes characterized by intermediate levels of resilience, i.e. intermediate habitat amount that still maintain a certain level of connectivity. These landscapes shelter high levels of biodiversity, which has the potential to recolonize restored areas. However, landscapes with intermediate levels of resilience are also at higher risk for species extinctions from habitat loss and fragmentation (Pardini *et al.* 2010; Martensen *et al.* 2012). When resilience is high, i.e. with high habitat cover and connectivity, landscapes have high potential to maintain biodiversity and to recover by autogenic processes, reducing the need for investments in restoration actions (Hobbs 2007). When resilience is too low, i.e. low habitat cover and connectivity, the cost of restoration might be too large and the probability of getting any conservation benefit would be very low due to the large proportion of species loss and the low probability of recolonization. This association of landscape cover and connectivity with biodiversity conservation and landscape resilience has great potential to help restoration practitioners distinguishing areas that would most benefit from restoration actions from those that are capable of recovering without intervention (Hobbs 2007).

Although some studies have recognized the importance of large-scale processes in restoration, there are few large-scale manipulative studies (Holl *et al.* 2003) and few restoration projects that have adopted a landscape perspective (but see Stanturf *et al.* 2012). The relationship between landscape structure and restoration effectiveness can be influenced by several factors, such as the type of habitat that was restored, land use history, the frequency and intensity of disturbance, the system resilience, the management protocol, and the method used to associate landscape structure to restoration outcomes.

In order to provide an overview of how landscape ecology has been incorporated in ecological restoration projects, we performed a literature review to explore the effects of landscape characteristics on restoration outcomes. Although

restoration ecology is a practical and multidisciplinary science with many objectives based on ecological, social, economic and cultural values (Clewell & Aronson 2013), we are here basically interested in the effects of restoration actions for biodiversity conservation, rather than on ecosystem services (Chazdon 2008; Rey Benayas *et al.* 2009) or on socioeconomic or public policy aspects (e.g., Aronson *et al.* 2010). We analyzed four groups of restoration attributes, which can affect the relationship between landscape structure and restoration outputs: (1) environmental conditions of restored landscapes; (2) disturbance characteristics; (3) restoration strategy and monitoring methods; and (4) methodological procedures to analyze how landscape structure influences the restoration effectiveness. We also investigated when landscape structure is more important for restoration effectiveness. According to Tambosi *et al.* (2014), in intermediate resilience landscapes we expect that the influence of the landscape context on the restoration outcome is easily detected. In extreme scenarios of landscape resilience, the landscape structure would not be so important, because at one extreme recolonization and regeneration is high and is not limiting organism flow, and at the other extreme, landscape connectivity is so low that it impedes recolonization.

Methods

We performed a survey for scientific articles in the Web of Science (Science Citation Index Expanded database, <http://portal.isiknowledge.com/>) and Scopus (Life Science database, <http://www.scopus.com>), using the keywords “landscape AND ecolog* AND restor*” in title, abstract and keyword fields. We limited the search period to between 1997 and 2011 because we consider the studies from the mid-1990s to represent the first insights on the application of landscape ecology principles to restoration. We also limited the search for scientific articles (avoiding grey literature, e.g. technical reports) not only due to access facility but also to consider more consolidated concepts and focus on results that had been peer-reviewed.

All the papers' abstracts were first evaluated to classify the study in one of the five main categories of landscape application to restoration: i) methodological; ii) conceptual contribution; iii) landscape recognition: landscape structure is not considered when planning or evaluating restoration outputs, but its importance is qualitatively recognized; iv) landscape assessment (LA): restoration is performed locally, but the outcomes are evaluated *a posteriori* based on the landscape structure; and v) landscape restoration (LR): the restoration is performed in large, heterogeneous areas, taking into consideration both landscape structure and dynamics. In the LA class, studies were also classified as passive (LAp) or active (LAa) restoration actions (*sensu* Holl & Aide 2011). Passive restoration studies are those characterized by very low human intervention such as regeneration of abandoned or degraded agricultural areas or removing/controlling disturbances in order to allow for

natural recovery. In contrast, active restoration studies involve more intensive human mediation on the restoration process.

Afterwards, all applications (LA and LR) were surveyed in order to collect information related to the four main groups of landscape/restoration attributes we had selected (see Table 1 for a detailed description), namely (A) environmental conditions of landscapes undergoing

restoration: continent, climate and type of restored habitat; (B) disturbance characteristics: previous land use, disturbance type, intensity and frequency; (C) restoration strategy and monitoring methods: restoration strategy, type and number of reference systems, method used to measure restoration success, restoration age, monitoring frequency, monitoring parameters and restoration results; and (D)

Table 1. Parameters used for the analysis of landscape restoration studies and their respective descriptions/categories.

Parameters used for analysis		Description/Categories
General	1. Publication year	from 1997 to 2011
	2. Continent	Africa; Asia/Oceania; Europe; North America; Central/South America
	3. Climatic Zone	Temperate; Tropical
(A) Environmental conditions	4. Habitat	Terrestrial habitats: Forests; Grasslands/Savannas Ecotonal habitats: Riparian Forests; Seacoast Aquatic habitats: Wetlands; Rivers
	5. Previous land use	Agriculture/Pasture; Forestry; Urbanization; Drainage/Impoundment; Mining; Natural habitats
(B) Disturbance Characteristics	6. Type	Habitat loss/Fragmentation; Degradation of aquatic environment; Fire; Natural disturbances (earthquake, hurricane, etc.); Biological invasion; Pollution; Others
	7. Intensity	Low (disturbance causes small changes on biotic components of the landscape); Medium (disturbance causes small changes on abiotic components, and big changes on biotic components of the landscape); High (disturbance causes high alteration on abiotic and biotic components of the landscape)
	8. Frequency	One-time; Constant
(C) Restoration management and monitoring methods	9. Type of restoration	Landscape restoration (LR); Landscape assessment for active (LAa) or passive (LAp) restoration
	10. Restoration strategy	From the less to the most intense: Abandonment and disturbance control to facilitate natural regeneration; Biotic manipulation only (for example, tree planting, vegetation thinning, weed control); Abiotic manipulation only (for example, fertilization, drainage removal, soil terrace implementation); Abiotic and Biotic manipulation
	11. Type of reference system	Positive (pristine or desired system); Negative (degraded system); Theoretical reference (knowledge or expectation about the structure and functioning of a healthy system, but without a field reference). The reference system could be <i>local</i> (located in the same landscape) or <i>regional</i> (located faraway or in another landscape).
(D) Landscape characteristics	12. Reference system replication	No replication; 1-2 replicates; > 3 replicates
	13. Success measurement	Reference system comparison; Before/After analysis (parameters compared before and after restoration); Temporal variation (development of parameters measured only after restoration); Treatment comparison (parameter comparison among different treatments and/or reference systems).
	14. Restoration age	Young (< 5 years); Intermediate (6-9 years); Old (> 10 years)
(D) Landscape characteristics	15. Monitoring frequency	One-time (parameters measured only once); Short (parameters measured from one to four years); Medium (5-10 years); Long (11 years or more)
	16. Monitoring parameter	Species diversity; Vegetation structure; Ecological processes (e.g. nutrient cycling, pollination); Population parameters; Abiotic structure;
	17. Restoration results	Positive; Negative; No change; Not evaluated
(D) Landscape characteristics	18. Landscape parameters	Landscape-level: Configuration (heterogeneity and complexity); Composition (number of habitat types); Habitat-level: Connectivity; Habitat cover; Patch density Patch-level: Isolation, Patch size; Patch shape; Edge type/density
	19. Landscape resilience	Classified according to the proportion of natural habitat in the landscape informed by authors or obtained from maps or secondary information on the article: High (>50%); Medium (20-49%); Low (<20%); NA (not available)
	20. Landscape influences on restoration	Detected influence of each landscape parameter on restoration results: Yes; No; Not Evaluated. The studies were also classified according to the presence or not of statistical tests to evaluate the landscape influence on restoration results.

landscape characteristics: parameters considered in the analyses (divided in three levels: patch, habitat or landscape), landscape resilience based on habitat cover, and effects of landscape structure on restoration results. We classified restoration strategy (parameter 10 in Table 1) from the least to the most intensive intervention on the landscape (from abandonment and disturbance control to both biotic and abiotic manipulation). We considered biotic manipulations to be those interventions characterized by species manipulation or control (e.g. tree planting, population control, species reintroduction). Although in several cases of biotic manipulation there are also abiotic modification such as soil correction, fertilizations and shade improvements, these studies were classified as biotic manipulation. The abiotic manipulation studies were those mainly characterized by physical modification in the landscape without biotic manipulation (e.g. engineering interventions in river channels, soil reposition in query sites).

To assure consistency in all steps of the classification described above, each paper was assessed by at least two readers. When there were doubts or a lack of concurrence between readers' classification, papers were read by all authors to reach a consensus.

We analyzed whether the impact of landscape on restoration outcomes depends on the restored site's conditions. To do so, we examined whether the number of studies that detected landscape effects on restoration results was influenced by the different classes of: disturbance intensity (parameter 7 in Table 1), restoration strategy (parameter 10), monitoring parameters (parameter 16), and landscape resilience (parameter 19). We also analyzed the relationship between local disturbance intensity (parameter 9) and landscape resilience (parameter 19) in order to verify if intense local disturbances are associated with low resilience landscapes. Due to the small number of studies selected by our survey (see results), we were not able to conduct statistical analysis. Results are thus presented in number and percentages of studies (N, %) by category on each item. Some items allowed more than one category per paper (e.g. type of perturbation, landscape attributes), thus, the number of cases for each category is sometimes higher than the number of studies.

Results and Discussion

General patterns

From a total of 1970 abstracts analyzed, only 254 were classified into one of the five classes of landscape application to restoration. The majority of the studies (92; 36%) recognized the importance of the landscape to restoration efforts or assessment, but did not evaluate it (e.g. Burke 2001). A similar result was found by Holl *et al.* (2003, p. 493), in which study approximately 37% of the surveyed papers "[...] recognized the importance of large-scale ecological patterns and processes in influencing ecosystem recovery and restoration." There were 88 (35%) methodological and 20 (8%) conceptual articles, half of them being studies related to the selection of priority areas for restoration actions (e.g. Crossman & Bryan 2006; Moreno-Mateos & Comin 2010).

A total of 54 restoration articles (21%) explicitly used a landscape ecology approach in empirical studies (LA or LR; list of reviewed references in supp. mat.). Even in those cases, most restoration actions were performed at a local scale and landscape characteristics were considered only when evaluating the results (LA studies; e.g. Guerrero & Rocha 2010). This type of landscape assessment became more frequent after the year 2002 with a total of 43 articles, while landscape restoration studies (LR; e.g. Aviron *et al.* 2011) became more frequent only after 2007 and were reported in 11 articles (Figure 1).

More than 15 years after the insights provided in the mid 1990s on the role of landscape context in influencing restoration outcomes, the mutualistic relationships between landscape ecology and restoration ecology remain poorly explored, with few empirical studies that incorporate a landscape perspective in restoration actions. This was also found by Holl *et al.* (2003). Nevertheless, the great increase in empirical studies on landscape-scale restoration since 2007 shows a promising scenario for the years to come.

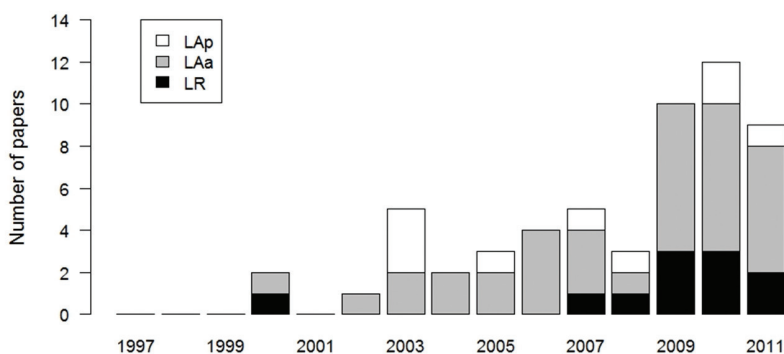


Figure 1. Number of empirical papers, per year, with a landscape restoration (LR) or with a landscape assessment for local active (LAa) and passive (LAp) restoration actions.

Characteristics of restored landscapes

The large majority of studies was carried out in temperate zones (47; 87%), concentrated in North America (22; 41%), followed by Europe and Asia/Oceania (14 each; 26% each). Only four studies were conducted in South/Central America (7%), and there was no study recorded in Africa. Forests were by far the most frequent ecosystem type considered (forests + riparian forests, N= 29), followed by wetlands and grassland/savannas (Figure 2). Our results reveal a large bias in geographical distribution with most of the studies conducted in developed and temperate regions. This can be related to a publication bias (i.e., there are less academic publications in developing countries), however, it can also be an effect of the habitual time lag between the beginning of new tendencies in scientific studies and the adoption of these tendencies in developing regions (Holmgren & Schnitzer 2004). Ruiz-Jaen & Aide (2005) and Aronson *et al.* (2010) also attribute this observed geographical bias to the existence of environmental laws and funding directed to restoration projects occurring almost exclusively in developed countries. Fortunately, some initiatives are emerging in developing countries, such as in Brazil where new laws are fostering ecological restorations (Aronson *et al.* 2011; Brancalion *et al.* 2010), which can accelerate the development of restoration projects and research.

Restored landscapes were mainly modified by habitat loss/fragmentation (42; 78%) (Figure S1a**), and previously occupied by agricultural/pasture activities (33; 48%) (Figure S1b). This trend was also reported by Dirzo & Raven (2003) and Ruiz-Jaén & Aide (2005). Forested landscapes were mostly restored with passive practices (Figure 2), which were responsible for the regeneration of temperate and tropical forests around the world (Chazdon 2008). In contrast, aquatic landscapes were frequently actively

restored (Figures 2 and 3; Ruiz-Jaén & Aide 2005), mainly because of the need to consider the whole watershed and reverse engineering modifications in order to guarantee the effectiveness of restoration (Chovanec *et al.* 2002; Rohde *et al.* 2005).

Twenty-two studies were conducted in sites under high intensity disturbance followed by 21 and 10 studies characterized by medium and low intensity disturbance, respectively. Thirty-three studies had ongoing disturbances, 19 presented one-time disturbance and two studies presented both disturbance categories.

Several authors recognize the importance of a reference system and control replications in ecological restoration projects (Ruiz-Jaén & Aide 2005; Clewell & Aronson 2013), and the majority of the studies (44; 69%) included some kind of reference system to compare restoration outcomes (Figure 4). A large percentage of studies adopted local positive or negative references, while few used regional or theoretical references (Figure 4). There were only three studies without reference system replicates and 22 studies with more than four replicates, including eight studies that had both negative and positive local reference systems.

The large majority of studies monitored restoration only once (36; 67%), followed by short (9; 17%), long (7; 13%), and medium (2; 4%) monitoring frequency (Figure S2). Intermediate and old restored systems were the most frequently monitored (22 and 20, respectively) and there were only 12 studies analyzing sites less than five years after restoration (Figure S2). Despite inadequate monitoring of restored landscapes, the tendency to evaluate older restored areas (> 10 years) can be a valuable source of information about restoration effectiveness since the early phases of restored site might be quite different in species composition and ecological processes when compared to mature reference sites (Clewell & Aronson 2013).

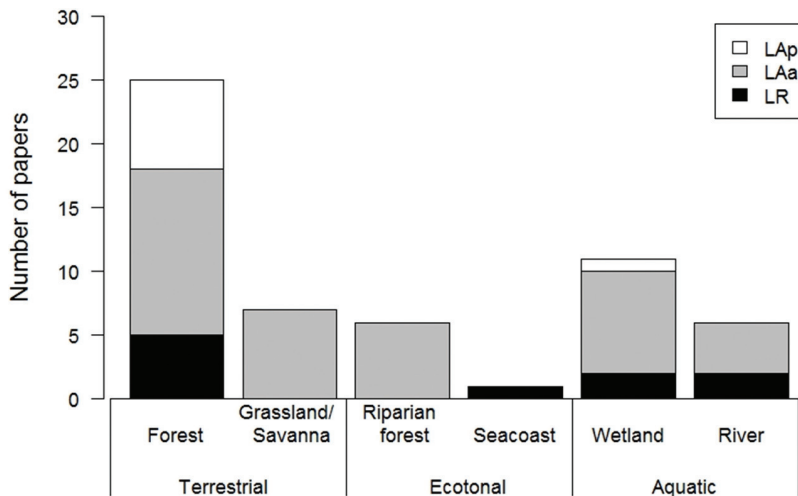


Figure 2. Restoration studies with a landscape approach (landscape restoration = LR, landscape assessment for local passive = LAp or active = LAa restoration actions) to different types of habitats.

**see supplementary material available at abeco.org.br.

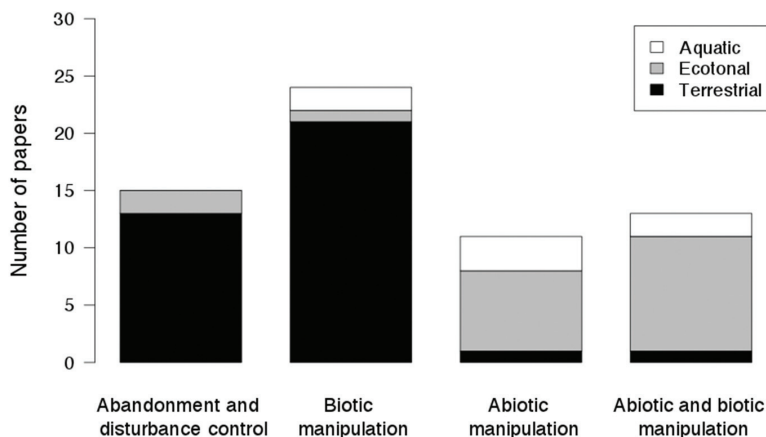


Figure 3. Number of studies in each class of restoration management according to different habitat classes.

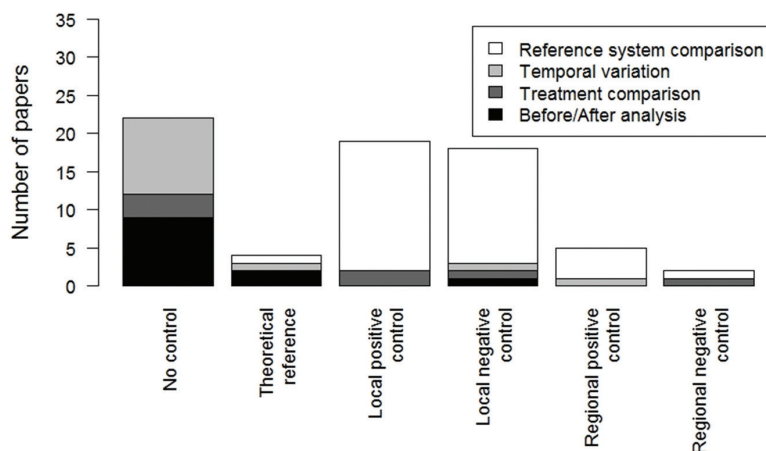


Figure 4. Relationship between reference system and success measurement in restoration studies with a landscape ecology application. For example, from the 22 studies that had no control, 9 of them used comparisons between before and after restoration to infer restoration success.

The main parameters used to monitor restoration outcomes were species diversity (30; 56%), vegetation structure (27; 50%), population parameters (16; 30%), followed by ecological processes (5; 9%), abiotic structure evaluation (3; 6%), community structure and landscape structure/composition (2; 4% each). A total of 96% of the studies used at least one of the three most common parameters (Figure S3) and 18 (33%) studies analyzed more than one parameter to evaluate restoration outcomes. The vast majority of papers evaluated the restoration outcomes as positive (47; 84%), while four studies reported no change in monitoring parameters after restoration and only one study reported negative effects after restoration.

Landscape characteristics affecting restoration

We were able to infer landscape resilience in 42 studies, and found that the majority of restoration activities were conducted in landscapes of intermediate resilience (19), followed by landscapes with low (16) and high resilience (7).

The most common landscape parameters (parameter 18, Table 1) considered in the restoration papers were related to the patch level (78; 47%), followed by habitat (46; 28%), and landscape (42; 25%) levels (Figure 5). Two levels of landscape attributes were analyzed by 23 studies and six studies analyzed all three levels (Figure S4).

The results clearly show that landscape structural parameters at any level are important, since most part of the studies detected at least one landscape characteristic that influenced restoration outcomes (Figure S5). These findings can be biased by the tendency of publishing only significant results (Fanelli 2012). Although, in our study this bias might be lower since most of the studies tested more than one landscape parameter, with some of them affecting restoration outcomes, and others not (Figure S5). Further, even if the results are biased, the availability of studies detecting the influence of landscape structure on restoration results highlights the importance of understanding the interactions between landscape characteristics and restoration outcomes.

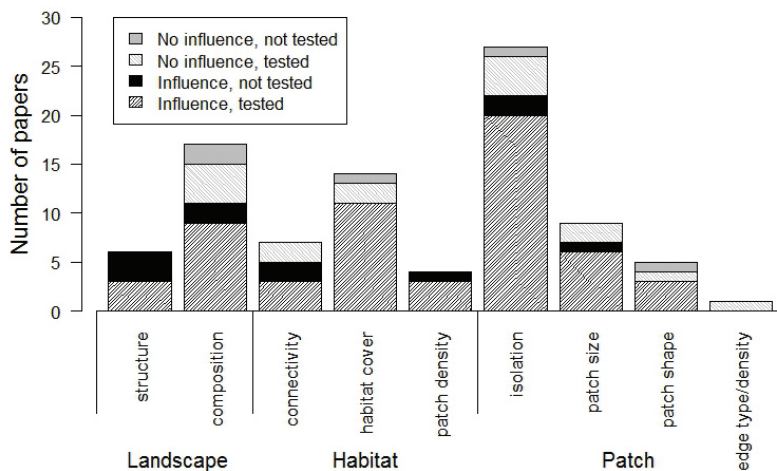


Figure 5. Frequency use of landscape parameters or indices (grouped by landscape, habitat and patch levels) and their influence (tested or not) on restoration outputs.

Landscape configuration and composition

At the landscape level, composition analyses were preferred over configuration analyses (17 and 6 studies respectively) and both influenced restoration results (Figure 5). Many studies found that more heterogeneous landscapes presented higher levels of species diversity and recolonization (Rannap *et al.* 2009; Gonzalez-Moreno *et al.* 2011; Li *et al.* 2011), resulting in higher improvements on species diversity in restored areas (Osland *et al.* 2011). Furthermore, landscapes characterized by higher percentage of agriculture can speed up vegetation succession due to high soil fertility (Matthews & Endress 2010) if propagules sources in the landscape are not too much reduced.

Habitat amount

The habitat cover in the landscape influenced restoration outcomes in 11 of the 14 studies that analyzed this parameter. In several studies the habitat cover had a positive influence in the recolonization of restored areas by many taxonomic groups (for examples, see Munro *et al.* (2009) for plants; Alsfeld *et al.* (2010) for plants and birds; Aviron *et al.* (2007) for butterflies).

Restored patch size was analyzed in nine studies and was often positively related to species richness and composition (Mulhouse & Galatowitsch 2003; Munro *et al.* 2009). This result could have been expected based on previous studies of species-area relationship (Watling & Donnelly 2006). However, in some cases, the restored patch size did not influence species richness, but rather, influenced native vegetation cover (Matthews *et al.* 2009; Munro *et al.* 2009), and exotic non-native occurrence (Matthews *et al.* 2009), which in turn hindered recolonization by native species. Patch size was also important in influencing natural succession, with smaller restored wetlands presenting higher species turnover, probably due to high extinction

probabilities in small restored areas (Matthews & Endress 2010). Moreover, smaller patches of *Pinus* in Sierra Nevada presented adequate conditions to facilitate recolonization by other plant species, which was also facilitated by more irregular patch shapes (Gonzalez-Moreno *et al.* 2011).

Edge effect

Although edge effects are frequently addressed in conservation studies, edge parameters were assessed only once in the studies we analyzed, and did not influence restoration outcomes. However, patch shape complexity was assessed by five studies, according to which, irregular patches had higher recolonization by plants, and also higher bird species richness and reproduction (Razola & Rey Benayas 2009; Selwood *et al.* 2009). Higher shape complexity might result in adequate microclimate and structural conditions for non-forest specialist species in the patch's edge (Fahrig 2003). These conditions might increase patch diversity, especially in degraded landscapes with a high number of non-forest species, since vegetation structure, microclimate conditions and availability of nesting sites can be important local limiting factors (Williams 2011).

Spatial arrangement

Patch density was assessed by four studies, and in all of them influenced restoration outcomes. Although usually associated with the deleterious effects of fragmentation, patch density (or the number of fragments) can also have a positive relationship with recolonization. For example, Thiery *et al.* (2009) showed higher diversity of recolonized aquatic species with higher density of wetland ponds in the landscape, probably because this higher density facilitates biological fluxes throughout the landscape. The spatial arrangement of the different landscape elements is also related to the probability of the occurrence of bird species

(Wood *et al.* 2004). A spatial arrangement that does not favor landscape connectivity can limit the recolonization of restored areas as detected for birds (Razola & Rey Benayas 2009), amphibians, invertebrates and fish species (Chovanec *et al.* 2002; Jähnig *et al.* 2009).

Connectivity was analyzed only in seven studies and did not influence restoration outcomes in two of them, although it was recognized as important in influencing several ecological processes in fragmented landscapes. This is probably due to the fact that connectivity is a species-specific measure, and is therefore difficult to take into account when monitoring several species or community responses to restoration actions.

On the other hand, patch isolation, which can be considered a more simplistic measure of the spatial arrangement of patches, and is also known to influence organismal flux in the landscape, was the most assessed landscape metric (27 studies). The isolation of restored patches affects restoration results by limiting plant, vertebrate and invertebrate recolonization in terrestrial (McLachlan & Bazely 2003), ecotonal (Alsfeld *et al.* 2010), and also in aquatic habitats (Tscharntke *et al.* 2005). Apparently simple at a first glance, the effects of isolation can be disguised by the choice of monitoring parameters. For example, Aviron *et al.* (2011) did not find influence of isolation over butterfly species abundance, but the isolation influenced butterfly species richness and composition, especially when analyzing specialist species (Aviron *et al.* 2007).

Landscape effects on restoration outputs

Most of the studies found that the landscape characteristics influenced vegetation structure (85%), species diversity (82%), population parameters (62%) and ecological processes (50%; parameter 16 in Table 1). We found that for many studies, the same landscape characteristic can influence some monitored parameters of restoration, such as vegetation cover, while other parameters (e.g. diversity) are not affected (Jähnig *et al.* 2009; Alsfeld *et al.* 2010).

Projects that adopted land abandonment and disturbance control strategy (parameter 10) were the most influenced by landscape structure (92% of the studies), followed by abiotic and biotic manipulation (89%), abiotic manipulation (78%) and biotic manipulation projects (63%). We consider that the small difference in landscape influence over different restoration strategies can be related to stakeholders that, empirically or intuitively, adopt management protocols and strategies adequate to the landscape characteristics. For example, land abandonment strategies are usually used in landscapes with high resilience (Lin *et al.* 2008; Cheung *et al.* 2010).

The percentage of studies reporting landscape influence on restoration outcomes tended to decrease as landscape resilience (parameter 19) increased. Parameters of landscape structure influenced restoration outcomes in 80% of the studies conducted in low resilience landscapes, followed by

70% and 62.5% of the studies in medium and high resilience landscapes. Furthermore, landscape influence on sites with low, medium and high local disturbance was detected in 70%, 75% and 79.4% of the studies, respectively. All three levels of local disturbance intensities were found in all landscape resilience categories, although low resilience landscapes were mostly affected by intermediate disturbance and intermediate resilience landscapes were mainly affected by high disturbance (Figure S6).

The observed impacts of the landscape on restoration outcomes for different disturbance intensities and levels of landscape resilience were surprisingly different from what we expected. In landscapes with high local disturbance, we expected local constraints to be much more important than landscape influence. In fact, we found that local constraints were considered the only, or the most important factor in several studies (Holl & Crone 2004; Grimbacher & Catterall 2007; Williams 2011) but these studies were usually restricted to medium and low local levels of disturbance. However, when restoration actions were able to overcome local constraints, landscape characteristics affected restoration results, including in the more severe degradation conditions such as previous mine sites (González-Alday *et al.* 2009; Costa *et al.* 2010).

The relationship between landscape resilience and landscape influence on restoration was different from the expected by Tamboosi *et al.* (2014). The resilience classification scheme adopted here is based on the amount of habitat cover, and is primarily supported by theoretical ideas (Andren 1994; Fahrig 2003) and empirical studies in tropical forests (Pardini *et al.* 2010; Martensen *et al.* 2012). One possible reason for the unexpected result is that resilience classes might be different for arid and semi-arid systems and for naturally fragmented habitats, such as wetlands and ponds. Beyond a potential misclassification of landscape resilience for such ecosystems, the low number of empirical restoration studies published in international journals that considered landscape structure does not allow a more robust conclusion on the effect of landscape resilience on restoration outputs.

Conclusions

To set realistic restoration goals, there are several issues that must be addressed in terms of landscape ecology and restoration ecology. This literature review shows that landscape characteristics influenced several ecological parameters that were used to monitor restoration outcomes. We also found that landscape characteristics can be as important as local site characteristics in influencing restoration effectiveness. When local limiting factor is overcome by restoration techniques, the importance of constraints at a different scale appears. Thus, both local and landscape parameters should be considered as potential constraints, which should be taken into account when planning and evaluating restoration actions.

Our review showed that the nature of the relationship between landscape structure and restoration outputs can be much more complex than expected. Particularly, we observed unexpected results relating local disturbance and landscape resilience with restoration effectiveness, and found that the same landscape parameter can positively affect some ecological parameter and not others (e.g. patch isolation did not affect butterfly abundance but did affect its richness and community composition in restored landscapes). For such situations, it is more difficult to define an appropriate landscape structure target for restoration actions or to select a reduced number of landscape parameters as indicators to guide restoration actions. We thus still need to better understand how landscape structure affects different ecological processes associated with restoration (e.g. recolonization, recruitment, dispersion, pollination, seed dispersal) to adopt effective actions to restore degraded landscapes.

Most of the reviewed studies showed that landscape structure can play an important role in restoration outputs, and thus, we advocate that researchers and restoration managers should combine landscape and local-scale approaches when planning restoration actions. By adopting this strategy and monitoring restoration results for landscape with different resilience and disturbance levels, we will be better able to understand the intricate interactions of local and landscape factors in influencing restoration outcomes, thereby optimizing future restoration efforts.

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