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Artificial perches promote vegetation restoration

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Abstract Native ecosystems are continuously being transformed mostly into agricultural lands. Simultaneously, a large proportion of fields are abandoned after some years of use. Without any intervention, altered landscapes usually show a slow reversion to native ecosystems, or to novel ecosystems. One of the main barriers to vegetation regeneration is poor propagule supply. Many restoration programs have already implemented the use of artificial perches in order to increase seed availability in open areas where bird dispersal is limited by the lack of trees. To evaluate the effectiveness of this practice, we performed a series of meta-analyses comparing the use of artificial perches versus control sites without perches. We found that setting-up artificial perches increases the abundance and richness of seeds that arrive in altered areas surrounding native ecosystems. Moreover, density of seedlings is also higher in open areas with artificial perches than in control sites without perches. Taken together, our results support the use of artificial perches to overcome the problem of poor seed availability in degraded fields, promoting and/or accelerating the restoration of vegetation in concordance with the surrounding landscape.

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Introduction

Native ecosystems are continuously being converted into anthropogenic areas for agricultural land use, pastures (Moran and Brondizio 1994; Griscom and Ashton 2011; Aide et al. 2013), infrastructure projects, mining, and fossil fuels extractive activities. At the same time, deforested fields are frequently abandoned after some years of use, due to degradation, loss of fertility, weed invasion, overgrazing, and rural exodus promoted by changes in the economies and policies

(Moran and Brondizio 1994; Cardoso da Silva et al. 1996; Holl 1998; Pejchar et al. 2007). Without any intervention, these abandoned fields usually show a slow reversion to native ecosystems, or to combinations of species known as novel ecosystems (Hobbs et al. 2006, Holl and Aide 2011). One of the main barriers to vegetation regeneration is poor propagule supply (McClanahan and Wolfe 1993, Martinez García and Howe 2003, Mansourian et al. 2005, Shoo and Catterall 2013, Elgar et al. 2014). Seed-rain and seed-bank data often show a strong decline in seed densities with distance from native ecosystem edges (Ingle 2003; Devlaeminck et al. 2005; Parejo et al. 2013). Even when abandoned fields are surrounded by native vegetation, only a small subset of species dispersed to the altered environment, and wind-dispersed species are usually over-represented (Cubiña and Aide 2001; Vicente et al. 2010; Zwiener et al. 2014).

Restoration programs that induced the entry of external propagule result in higher plant densities than those based just in the resiliency of the area. Thus, appropriate restoration programs are prioritizing conservation of biofunctionality. Degraded communities are redirected, integrating them with the surrounding remnants of landscape through an ecological flow (Bengtsson et al. 2003; Tres and Reis 2009; Reis et al. 2010). The conserved fragments near the degraded areas work as biotic and abiotic diversity source (i.e., nuclei). These nuclei can propitiate new populations inside the communities in restoration, creating new niches of regeneration or colonization (Yarranton and Morrison 1974; Reis et al. 2010; Corbin and Holl 2012). Nucleation techniques accelerate environmental succession, owning the expression of recovery mechanisms used by nature, reflecting their stochastic processes and resilience capacity (Reis et al. 2003; Sekercioglu 2007; Bechara et al. 2007; Tres and Reis 2009).

A large proportion of plants are dispersed by animals (Herrera 2002; Sekercioglu 2007), and seeds coming from adjacent native patches to open areas are essential for native vegetation to recover. Deposition of seeds through defecation and regurgitation happens more often when birds are perched or immediately after flying away (McDonnell and Stiles 1983; Vicente et al. 2010). Thus, a higher seed rain is generated under perches compared to open areas (Debussche and Isenniann 1994; Holl 1998; Rincón Guarín 2005; Tomazi et al. 2010; Vicente et al. 2010; Albornoz et al. 2013). Regeneration nuclei are created under perches (Guevara et al. 1992; Debussche and Isenniann 1994; Holl 1998; Tres and Reis 2009), promoting patches of vegetation that naturally continue irradiating up to occupy the empty spaces among them (Guedes et al. 1997; Melo et al. 2000; Reis et al. 2010; Dos Santos et al. 2011). Indeed, the presence or absence of recruitment points in the vegetation could deeply influence seed dispersal (Hooper and Bullington 1972; Ne'eman and Izhaki 1996; Holl 1998; Pausas et al. 2006; Cavallero et al. 2013). Fruit-eating species foraging in the native vegetation are not commonly found in open areas (Carlo and Yang 2011; Ponce et al. 2012; Mastrangelo 2014). Consequently, if few or no remaining trees have been left in altered landscapes, most seed dispersal would be restricted to native vegetation edges (McDonnell and Stiles 1983; Toh et al. 1999; Parrotta et al. 2007).

Based on the principles of nucleation, the setting-up of artificial perches has been proposed to facilitate the arrival of seeds in post-fire, burned and logged areas, landslides and mining zones, abandoned crop fields and pastures (McDonnell and Stiles 1983; McClanahan and Wolfe 1993; Rudge de Carvalho 2008; Cavallero et al. 2013). Artificial perches increase the structural complexity of the environment, making it more attractive for birds, encouraging them to fly out of the native vegetation and into the degraded area (Rincón Guarín 2005; Bocchese et al. 2008; Vicente et al. 2010; Graham and Page 2012). Apparently, artificial perches enable the establishment of pioneer plants (Jordano et al. 2006; Tomazi et al. 2010) and in some cases, the early appearance of "late-successional" species (Ne'eman and Izhaki 1996; Pausas et al. 2006; Tomazi et al. 2010). Another advantage of implementing artificial perches could be the fact that the composition of the vegetation cover would be similar to the surrounding areas because the seedlings come from these locations (Melo et al. 2000; Reis et al. 2003; Rudge de Carvalho 2008; Reis et al. 2010; Shiflett and Young 2010). Despite many restoration programs have already tested the usefulness and effectiveness of artificial perches, there is no consensus on the overall effects of the technique on bird-mediated seed dispersal and seedling growth. Here, we report the results of a series of meta-analyses to evaluate the magnitude of the effect of artificial perches used by birds on vegetation regeneration. Specifically, we ask three questions: (1) Do artificial perches increase seed rain in degraded landscapes? (2) Do artificial perches increase seed establishment in degraded landscapes? (3) Do artificial perches increase species richness of seeds in degraded landscapes?

Methods

Literature search

To obtain a comprehensive set of studies that conformed the specific criteria of our meta-analyses, we did keyword searches in Scopus, CAB Abstracts and Biological Abstracts databases and the first 400 results of Google Scholar. Search terms evolved from terminology used in the literature, and making active judgments to refine searches. Online search was conducted from June to August 2014 and the following search terms were used: "bird perch* AND seed dispers*". Keyword search was supplemented by reviewing references cited in papers already selected. We read tittles and abstracts for screening, if the articles dealt with artificial perches then we read the full text publication to determine eligibility for inclusion in the meta-analyses. Articles were checked and retained if they met the following requirements: (1) there is a treatment with artificial perches (isolated trees were excluded) and a corresponding control, with seed traps for both, (2) perches and controls were situated in a disturbed matrix adjacent to or near by the native ecosystems (we supposed the seed rain comes from there), and (3) means and standard deviations of seeds abundance where specified in each case (alternatively, we also accepted *t*-student with *P*-values and *F*-statics with *P*-values).

We compiled estimates of the amount of dispersed seeds directly from values reported in the text, tables or extracted from figures using the program DataThief (Tummers 2006). When it was possible, we contacted the authors and asked them to send the information not reported in the articles (standard deviations in most cases, and control means). We used the same set of papers to extract species richness of dispersed seeds and means of seedlings abundance. To facilitate future interpretation of the data or identify data gaps across studies, we also compiled information on the country, zone (tropical, subtropical or temperate), type of native ecosystem, type of matrix or disturbance, temporal and spatial extent of the experiment and distance to patch of native ecosystem.

Data analysis

The most common response surveyed for abundance of seeds and seedlings was density. We used means and standard deviation for perches and controls. We also used sample size, means and *t*-student (Tres 2006); sample size and *t*-student (Reis et al. 2010) and total sample size with *F*-test (Melo et al. 2000) converted to Coheńs paired *d* with confidence interval.

For both variables, we performed calculations in Comprehensive Meta-Analysis (CMA version 2.2.064) (Borenstein et al. 2009) according to random-effects model (because we would often expect the true effect to vary among studies). For each pair-wise comparison, we obtained effect size as Hedges' *g* (the difference between means of perches group and no perches control group), standardized using the pooled standard deviation of the two groups. Effect size was defined as positive where a difference in the outcomes indicates higher seed rain, number of seed species or seedling establishment under perches, respectively. Effect size values below zero indicated that no perches control group was more beneficial to seed dispersal or seedling establishment than the perches group.

In some cases, the authors of the articles included in the meta-analyses had informed multiple results in the same article, as they measured the abundance of seeds and seedlings in different sites (Scott et al. 2000), at different distances from native ecosystems (Assunção 2006; Parejo et al. 2013) or using different kinds of artificial perches (Holl 1998). In Parejo et al. (2013), the seeds were classified as native and exotic, while in Carmona et al. (2010) the results were reported differentiating four species of plants. To avoid bias, we included only one result from these articles, combining and using the mean of all results. When the results were considered independent, we use each result as a different study in the meta-analyses (Hinman et al. 2008; McCay et al. 2008; Heelemann et al. 2012; Elgar et al. 2014). In case the article included multiple experimental treatments, we used only control data related with artificial perches as result (Bevilacqua Marcuzzo et al. 2013).

We examined heterogeneity in CMA by a Chi-squared test (*Q*) to assess the inconsistency in the effect sizes of artificial perches on seed and seedling abundances across the set of studies. The percentage of the total variation in estimated effects across studies that is due to heterogeneity rather than to chance (I^2) was also computed in CMA.

For species richness, papers report total number of seeds species dispersed in each treatment, instead a mean of species richness dispersed under each perch. For this reason, it was not possible to perform a meta-analysis and we calculate an effect size using each study as independent data.

Risk of bias across studies

We assessed the possibility of publication bias by evaluating funnels plot and fail-safe numbers for both meta-analyses in CMA. The funnel plots present effect size (Hedges' g) on the X axis and standard error on the Y axis. In the absence of publication bias, the studies represented in the plot will be distributed symmetrically about the mean effect size. Otherwise, the studies are expected to have symmetry at the top, a few studies missing in the middle, and more studies missing near the bottom. CMA incorporates "Trim and Fill" in the Funnel Plot so we can see how the effect sizes shift when the missing studies are included (Duval and Tweedie 2000a, b).

Rosenthal's fail-safe numbers compute how many missing studies with a zero effect size we would need to incorporate in the analysis before the P-values became nonsignificant. If only a few studies are needed to 'nullify' the effect (less than $5n + 10$, where n is the number of studies) then we would be concerned that the true effect was indeed zero. Orwin's fail-safe numbers ask how many missing studies it would take to bring the summary effect below a certain selected point, that represent the smallest effect deemed to be of substantive importance (here 0.100). It also allows specifying the mean effect in the missing studies as some value other than zero.

Results

In total, we found 15 articles that met the criteria indicated for seed rain, but considering the independent measures of some articles, we worked with 17 study cases. For seedling establishment, we found 9 articles and worked with 12 study cases. For species richness of seeds, we worked with 16 articles and 21 study cases (see Online Resource 1). Some other articles were also found relevant in their context but lacked the necessary data to conduct effect sizes calculations (see Online Resource 2).

Seed rain

Seed rain under artificial perches was greater than seed rain in open control sites without perches ($Z = 6.193$; $P < 0.0001$) as the overall effect size and its confidence interval were larger than zero (Hedgeś $g = 3.388$, 95 % CI 2.316–4.461, Fig. 1) (see Online Resource 3 and 4). The effect of artificial perches differed between studies ($Q = 221.832$, $df = 16.000$, P value $= 0.000$), with a high level of genuine variance between studies ($I^2 = 92.787$) (see Online Resource 4).

The articles were predominantly from countries of the Neotropics ($n = 9$) but there are articles also from North America ($n = 2$), Europe ($n = 2$), Asia ($n = 1$), and Africa ($n = 1$), with no studies from Oceania. Seven articles (46.6 %) were undertaken in subtropical zones; other five articles (33.3 %) in tropical zones and just three (20 %) were in temperate zones. The type of altered environment included abandoned agricultural fields, active or abandoned pastures, burned and logged areas, exotic conifer and

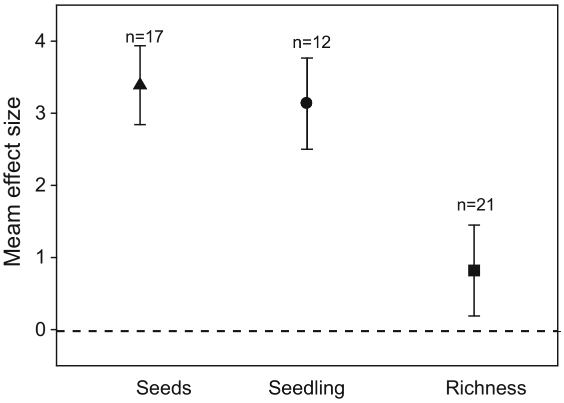

Fig. 1 Results from the meta-analyses showing the positive effects of seed dispersal (*triangle*), seedling establishment (*circle*) and species richness (*square*). If the CIs do not overlap the horizontal line at 0, then there is a significant positive effect of the presence of perches on that aspect of seed dispersal, seedling establishment and richness

eucalyptus plantations, landslides, and mining zones. The temporal extent of restoration experiences ranged from 4 to 24 months, while spatial extent ranged from 0.03 to 87.20 ha. The distance of the perches from the edge of the native ecosystem patch ranged from 5 to 2500 m (see Online Resource 5).

Seedling establishment

Seedling establishment was greater under perches compared with open control sites without perches ($Z = 4.958$; $P < 0.0001$) (Hedgeś$g = 3.133$, 95 % CI 1.894–4.371, Fig. 1) (see Online Resources 3, 4). Variation in effect sizes was statistically significant ($Q = 221.832$, $df = 11.000$, P value $= 0.000$), with a high proportion of variance reflecting real differences among studies ($I^2 = 94.900$) (see Online Resource 4). The set of articles with seedlings measures were mostly from countries of Neotropics ($n = 6$), also include articles from North America ($n = 2$) and Oceania ($n = 1$). Temperate zones were also the least represented (11.1 % of the articles, compared with 55.5 % of subtropical and 33.3 % of tropical zones). Temporal extent of restoration experiences ranged from 7 to 36 months, while spatial extent ranged from 0.03 to 64 ha. The distance of the perches from the edge of the native ecosystems patch ranged from 5 to 300 m (see Online Resource 5).

Species richness

Species richness of seed rain was also higher under artificial perches than in control sites without perches (Hedgeś$g = 0.82$, 95 % CI 0.190–1.449, Fig. 1). The articles of the analysis were predominantly from countries of the Neotropics ($n = 11$), while the rest of the experiences included were from Europe ($n = 2$), North America, Africa, and Asia ($n = 1$). Following the tendency observed for seed rain and seedling establishment set of articles, temperate zones were the least represented with just three articles (18.75 %), tropical zones were undertaken in six articles (37.5 %), and subtropical zones in seven (43.75 %). Temporal extent, spatial extent, and distance of the perches from the native ecosystems edge in the experiences covered the same wide range as seed rain studies (range: 4–24 months, 0.03–87.20 ha, and 5–2500 m, respectively) (see Online Resource 5).

Risk of bias across studies

The funnel plots obtained showed that the direction of the effects is in both cases toward the right side (positive effect sizes). Trim and Fill indicated that the incorporation of missing studies in the left side of the plot produced trivial shifts in the effect sizes. The key findings of the meta-analyses remained unchanged for seed dispersal. In the case of seedlings establishment, the values decreased but remained positives (Hedgeś$g = 2.719$, 95 % CI 1.485–3.953) (see Online Resource 6). Rosenthal and Orwin's fail-safe numbers pointed out that we needed a large number of studies to nullify the positive effects observed (1559 and 388 for seed dispersal; 779 and 211 for seedling establishment). Thus, we considerate that the impact of bias is probably negligible and of minor concern. Besides there were few articles meeting the requirements for inclusion in the meta-analyses, the trends detected in the review are robust.

Discussion

The results of our meta-analyses showed that artificial perches promote vegetation restoration of degraded landscapes. The use of artificial perches by birds facilitates the arrival of larger and more diverse seed rain, promoting the establishment of seedlings in degraded open areas. The fact that artificial perches increase the abundance of the seed rain in altered areas is crucial considering that a large proportion of seeds will not survive and the availability of propagule source does not always reflect larger seed rain (White et al. 2009; Graham and Page 2012; Reid and Holl 2013; Zwiener et al. 2014). Consequently, restoration programs that induced the entry of propagule result in higher plant densities than those based just in passive restoration (Toh et al. 1999; Tres and Reis 2009; Schorn et al. 2010).

The use of artificial perches also generated an increase in the number of species present in the seed rain entering to open areas. In addition, taking into account that initial species will have a decisive effect on the future succession in the landscape (i.e., priority effect), not only the number and identity of seed species but also the functional types of the seeds that first arrive to the site are essential (Mansourian et al. 2005). In that sense, predominance of anemochorous seeds can retard or even modify the process of native vegetation restoration. On the other hand, carry out seeding by sowing seeds directly on bare land can also fail in selecting the appropriate plant species, conditioning, and threatening natural succession. Artificial perches make possible a biological flow from neighboring remnants of native ecosystems, directing ecological succession, and enabling a vegetation similar to the original (McClanahan and Wolfe 1993; Reis et al. 2003; Tres and Reis 2009; Schorn et al. 2010).

The higher abundance of seedlings registered under artificial perches support the idea of considering propagules source as one of the main problems to native ecosystems regeneration. Then, the difference between effect sizes of seed dispersal and seedling establishment, and the high proportion of variance in seedlings abundance among studies, may be associated with barriers to overcome after seed dispersal (Aide and Cavelier 1994; Debussche and Isenniann 1994; Toh et al. 1999; Cubiña and Aide 2001; Vicente et al. 2010; Reid and Holl 2013). In addition, the low number of studies including seedlings abundance highlights the lack of complete monitoring for experiences of restoration. Monitoring seedling recruitment requires less effort than seed dispersal sampling (taking in account that seedlings may be measured at the beginning and at the conclusion of an experiment), but more than that it can be considered as an indicator more appropriate for restoration initiatives effectiveness (Reid and Holl 2013).

Compared to traditional reforestation programs and according with several authors, the installation of artificial perches requires less manpower and has been pointed as one of the cheapest nucleation methods (Holl 1998; Scott et al. 2000; Corbin and Holl 2012; Graham and Page 2012; Shoo and Catterall 2013). Unfortunately, the most common technique used for vegetation restoration is reforestation. This is a complex and more expensive strategy of restoration, taking into account the costs of obtaining, storing, refrigerating, desiccating, raising, and planting the seedlings in the restoring sites. For example, in the case of late-successional species, the cost can be even higher, considering that their seeds are generally bigger than pioneer ones, not dry and more difficult to store and germinate (Mansourian et al. 2005; Corbin and Holl 2012). Meanwhile, cost associated with applied nucleation is substantially lower due to focussed efforts within punctual areas, leaving the other ones to be colonized with new recruits as nuclei expand (Corbin and Holl 2012). Moreover, reforestation plans are usually conducted with only one or a small number of species, limiting the structural variability and the ecological benefits of the restored community (Mansourian et al. 2005; Griscom and Ashton 2011).

In conclusion, the use of artificial perches is a good management practice capable of overcoming the problem of poor seed arrival in a wide range of degraded native ecosystems, promoting and/or accelerating the first steps in the process of native vegetation restoration. This nucleation technique increases the number and richness of seeds that arrive at the altered matrices surrounding native ecosystems. The seed rain under perches induces and directs natural succession in open areas, giving rise to recruitment nucleus with higher density of seedlings, which can progressively spread out regenerating native vegetation. Compared to other active restoration techniques, the installation of artificial perches favors the expression of recovery mechanisms used by nature, integrates the restoring area with the surrounding remnants of landscape, besides being low-cost and easy to carry out.

The most appropriate restoration approach probably depends on a careful evaluation of ecological circumstances such as the fertility of soils, the extent of degradation, the proximity of remaining native ecosystems, species involved, seasonality, and socioeconomic circumstances. Other nucleation techniques complementing artificial perches could also serve to overcome the obstacles after dispersion, bridging the gap between numbers of dispersed seeds and established seedlings.

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