Meli, P., Martínez-Ramos, M., Rey-Benayas, J.M., Carabias, J. & Ewald, J. 2014, "Combining ecological, social and technical criteria to select species for forest restoration", Applied Vegetation Science, vol. 17, no. 4, pp. 744-753.

Available at http://dx.doi.org/10.1111/avsc.12096

(Article begins on next page)

Combining ecological, social and technical criteria to select species for forest restoration

Paula Meli, Miguel Martínez-Ramos, José María Rey-Benayas & Julia Carabias

Meli, P. (Corresponding autor, paula@naturamexicana.org.mx): Natura y Ecosistemas Mexicanos A.C., San Jacinto 23-D, Col. San Ángel, México D.F., 01000, México.

Martínez-Ramos, M. (martinez@cieco.unam.mx): Centro de Investigaciones en Ecosistemas, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701, 58190, Morelia, Michoacán, México.

Rey-Benayas, J. M. (josem.rey@uah.es) & **Meli, P.**: Universidad de Alcalá, Edificio de Ciencias, Departamento de Ciencias de la Vida, 28871, Alcalá de Henares, Madrid, Spain.

Carabias, J. (jcarabias@ecologia.unam.mx): Departamento de Ecología y Recursos Naturales, Facultad de Ciencias, Universidad Nacional Autónoma de México, Av. Universidad 3000, Circuito Exterior S/N, 04510, México D.F., México.

Running head: Selecting species for forest restoration.

Type of article: Research paper.

Abstract

Question: How to evaluate and integrate relevant ecological, social and technical criteria to select species to be introduced in restoration projects of highly diverse ecosystems such as tropical riparian forests?

Location: Riparian forest, Marqués de Comillas municipality, southeastern Mexico (lat 16º54'N, long 92º05'W).

Methods: We proposed a "Species Selection Index" (SSI) using five independent criteria related to ecological, social and technical information. SSI targeted species that (1) are important in the reference forest, (2) are less likely to establish following disturbance, (3) are not specific to a particular habitat, (4) are socially accepted, and (5) their propagation requires a reasonable time and financial investment. SSI may range between 0 and 50, with higher values meaning higher potential for restoration purposes.

Results: Out of a local pool of 97 species, we identified 30 target tree species that together represented >60% of total Importance Value Index in the reference riparian forests. SSI averaged 28.3±1.0 over the studied species, suggesting that species with high values are not frequent. For twenty species, reintroduction by means of active forest restoration was deemed necessary. Species that established through natural regeneration, following secondary regrowth, had lower social value among local farmers. Nearly half of the identified species showed technical constraints for easy propagation and seeding.

Conclusions: The proposed procedure is useful for selecting species to initiate forest restoration projects and of other woody ecosystems that harbor high biodiversity, and is suitable for several stakeholders interested in restoration.

Key words: Indicators; Mexico; Natural regeneration; Propagation; Revegetation; Social value; Tropical riparian forest.

Introduction

The re-establishment of native plant species is a widespread tool in ecological restoration, but in many ecosystems such as forests in the humid tropics, the large regional species pool makes it difficult to effectively identify target species for restoration projects. Thus, a systematic approach is desirable to screen the widest possible range of native taxa for possible inclusion in restoration programs (Knowles & Parrotta 1995). Species selection requires extensive background studies, and sometimes monitoring of hundreds of species through several years (Knowles & Parrotta 1995; Blakesley et al. 2002a, 2002b; Elliott et al. 2003). However, restoration projects usually require short-term results with limited economic resources. Therefore, once the main objectives of restoration efforts based on a census of all stakeholders have been defined, the generation of a list of target species for revegetation (Brudvig & Mabry 2008) should be accomplished.

There is a wide variety of criteria to select target species for forest restoration. They depend on the ecosystem to be restored and the particular needs of each project. For example, in Australia and Thailand, the “Framework Species Method” (FSM) selected species with ecological properties such as (i) high survival and growth rates in degraded sites, (ii) dense crowns that shade out herbaceous weeds, (iii) provision of resources that attract seed-dispersal vertebrates at early restoration age, and (iv) germination traits enabling easy propagation in nurseries (Blakesley et al. 2002a, 2002b; Elliott et al. 2003). In India (Sharma & Sunderraj 2005) and Brazil (dos Santos et al. 2008), species were selected based on their natural regeneration capacity. However, besides ecological criteria, other criteria related to social acceptance and technical feasibility for propagation are required to optimize identification of suitable native species for restoration.

We distinguished tree species that were passively restored by natural regeneration from those requiring active restoration in a previous study based on ecological criteria, namely dominance and regeneration potential (Meli et al. 2013a). However, given that biodiversity conservation and ecological restoration must embody societal values to improve their success (Garibaldi & Turner 2004), it is critical to recognize and take into account the cultural perceptions and acceptance of the species used in restoration projects. Successful restoration actions need the participation of local stakeholders, and the potential of species to be used in such actions should be evaluated not only on the basis of their ecological traits but also on criteria that consider both social benefits and technical limitations such as germination and propagation requirements under nursery conditions. In this study, we propose a procedure to select target species for forest restoration projects, which is illustrated by a case study related to restoration of Neotropical riparian forest. This work does not constitute a framework for implementing restoration activities (SER 2004). Rather, it pursues (1) the identification of the species pool at a reference ecosystem, (2) the selection of species from this pool based on ecological, social and technical criteria that are considered relevant for restoration, and (3) the integration of such criteria into a single and operational Species Selection Index. It aims to link the ecology and management of degraded forests and to be suitable for implementation by various stakeholders in forest restoration efforts. We also discuss the potential implementation of the proposed procedure in other ecosystem types and in scenarios with uneven information availability related to social values and technical requirements. We finally bring out some suggestions that could be addressed by future studies of species selection for restoration of tropical riparian forests and other species-rich ecosystem types.

Study site

We conducted this study at the Marqués de Comillas (MdC) municipality (16º54'N, 92º05'W), Selva Lacandona region, southeastern Mexico. Its climate is typically hot (25°C annual mean), with a mean annual precipitation of ca. 3,000 mm and a short dry season (<100 mm month^{-1}) between January and April. Due to its diversity of soil types, heterogeneous topography (Siebe et al. 1995) and complex fluvial network, several tropical ecosystems are present in this municipality but rainforest is the dominant one. Although the Maya and other human groups inhabited and abandoned this municipality more than 500 years ago, human colonization restarted in the early 1970s, when governmental programs encouraged immigration and this settlement has been portrayed as spontaneous and unorganized (De Vos 2002). Former old-growth forest has been extensively converted to agricultural fields. Deforestation also includes riparian vegetation, which impacts both terrestrial and aquatic ecosystems. MdC adjoins Montes Azules Biosphere Reserve across the Lacantún River, and shows a complex net of permanent and temporal streams. Therefore, the conservation of remnant old-growth forest in the region has been recognized of high priority, both in Mexico and Guatemala (Mendoza & Dirzo 1999).

Methods

Procedure and criteria

To obtain a list of target species for the revegetation of riparian degraded zones, we considered five criteria that are based in ecological, social and technical information (Table 1).

1. Natural species dominance (D). This criterion evaluates dominance of individual species in the reference forest, which in our case was represented by six sites with pristine old-growth riparian forest. Sites were identified through prospective routes along streamsides. We estimated relative density, relative frequency and relative basal area of all woody species with dbh $\geq$ 0.5 cm along a 50 x 10 m transect parallel to the stream in each site. Basal area was estimated using the diameter at breast height (dbh) and the formula π*(dbh*0.5)^2 assuming a circular shape of the stem cross plane. For each transect and species, we calculated an Importance Value Index as the sum of relative density, relative frequency, and relative basal area of a species divided by three (IVI_i; Curtis & McIntosh 1951). The measured IVI_i was used as an indicator of D and adopted values between 0 and 100.

2. Natural regeneration potential (NRP). This criterion evaluates the potential of the species to re-establish after disturbance and was first elaborated by Meli et al. (2013a). To quantify NRP we used five sites representing the typical secondary riparian forest. This secondary forest grew on sites formerly covered with old-growth forest similar to the studied reference forest that was totally deforested and abandoned later. Age of the secondary forest sites varied between 3 and 10 years. In equal transects (50 x 10 m each) as in reference forest sites, we obtained for every species their abundance (N_i, number of stems of species i per transect) in each of ten dbh classes (range: 0.5 to >50cm, class intervals: 5-cm). For each transect and species, we calculated the correlation (Spearman rank correlation, r_s) between abundance [log (Ni +1)] and the mid-point of the dbh classes (hereafter called abundance-size correlation). A high NRP is represented by a diminishing number of individuals as diameter sizes increase; this change will result in a significant negative correlation and therefore an acceptable potential for passive establishment of the species (Meli et al. 2013b). A null or a positive correlation for a particular species indicates

that it does not establish naturally (i.e., lack of regeneration) and, therefore, it needs to be actively restored or reintroduced. We focused on the last kind of species considering that in our study site the establishment of some species could be impeded or slowed down by physical, chemical or biological barriers (Holl 2007). The NRP is a continuous variable that varied between -1 and 1.

3. Habitat breadth (H). This criterion is a surrogate of the ability of the species to develop in habitats of different geomorphology, which differ in soil and topographical properties. We assumed that species found in more habitats have higher ability to establish after disturbances. Selecting those species with higher habitat breadth implies selecting generalist species, which may be detrimental for riparian-specialist species. However, we envisage the selection of generalist species as an initial restoration step that will lead to the rapid establishment of an initial canopy, thus creating the environmental conditions for the re-establishment of specialist species in a later step. This criterion selects widespread, but not necessarily abundant species. We used data from 14 permanent 20 x 250 m plots that were previously established within five geomorphological units that differed in soil and topography in pristine rainforest: floodplain, karst, alluvial, savanna, and low-hill rainforest (Siebe et al. 1995). We then counted the units where each species occurred. As H is an ordinal criterion, it ranged between 0 and 5.

4. Social value (SV). This criterion identifies locally salient species that shape the perceptions of local people with respect to (i) the natural abundance of the species in the riparian forest (in a rank of 0 to 5), and (ii) the local values of species for provision of food, materials, medicine, and/or cultural practices (Garibaldi & Tucker 2004). These two components of the SV in our study are comparable because the number of different use types never exceeded four (see below). The information related to these two aspects was confirmed from participatory interviews with

farmers in four local communities. In groups of four or five persons each, they shared photos of the 30 species with highest IVI_i at reference forest sites (Appendix S1). Farmers were also consulted about other suitable species for riparian restoration that were not included in the previous list. The SV was calculated as the rank of abundance plus the number of local use types; as SV was an ordinal variable, it took on values >0.

5. Technical constraints (Tc). We collected seeds in the field, and germinated and propagated them in a nursery, for all available species of those selected 30 species with highest IVIi at reference forest sites, and then scored these species. This criterion identifies cost-effective techniques for successful species propagation. We used our own data in an adapted scoring system from Knowles and Parrotta (1995) that included three aspects with three categories each: (i) ease of seed collection (combining seed size and dispersal syndrome: large and zoochorous, small and zoochorous, and small and anemochorous/hydrochorous; note that seed availability is included in this component of Tc); (ii) seed germination treatment requirements (none, mechanical and chemical treatment); and (iii) alternatives for introduction in field (direct seeding, wildlings/stumps, seedlings produced in nurseries; Appendix S2). The categories received numerical values (1 to 3) with higher values for the easiest/lowest cost option and lower values for the most difficult/expensive options. These three values were added; as Tc was an ordinal variable, it ranged between 3 and 9.

Assembling the index

Considering that some criteria were continuous and other were ordinal, and that they varied at different scales, to make them comparable we calculated the Z score for each criterion by obtaining the difference between a datum value and the mean of the variable and dividing this difference by the standard deviation. Finally, we divided these individual Z scores into ten classes from <-2 and >2, with 0.5 class intervals. We assigned a value of 0 to the lowest class and 10 to the highest class. We considered all criteria equivalent and calculated SSI using the following formula: SSI = D + NRP + H + SV + Tc. This SSI is an ordinal variable that ranges between 0 and 50.

To explore possible relationships among the five criteria we performed non-parametric correlations (Spearman r_s) across the normalized data (Z scores) of all criteria.

Results

Criteria values

A total of 97 species were found in the reference forests, of which *Ficus* sp. had the maximum IVI_i (11%) and only ten species had an IVI_i > 2% (Table S1). We found 92 species in the disturbed forests, of which *D. guianense* had the maximum IVI_i (5%) and only fourteen species had an IVI_i > 2% (Table S2). The first fifteen species accumulated 50% of total IVI in the reference sites (Fig. 1a) and 48% in the disturbed sites (Fig. 1b). We restricted all our analysis to those 30 species that showed the highest IVIi, in the reference sites which together covered > 60% of the total community IVI.

Eight out of these 30 dominant species showed negative abundance-size correlation coefficients ($r_s < -0.6$, $p < 0.05$), which suggested that passive restoration could be sufficient for their successful establishment (Table S3). Twelve species did not occur at disturbed sites and ten species showed a non-significant abundance-size correlation, thus hinting to the necessity of introducing them by means of active restoration.

More than half of the species occurred in three or four geomorphological units (54%), whereas nine species occurred in one or two (30%) and only three species (*B. alicastrum*, *D. guianense*, *P. copal*) occurred in all geomorphological units (10%; Fig. 2, Table S3). Two sampled species (6%) were totally absent in the five geomorphological units (*M. glaberrima* and *N. sleneri*).

Farmers recognized most of the species (80%; Appendix S1). Ten species (33%) were recognized in all cases, while seven species (23%) were mostly unknown. In general, farmers notably distinguished Lacantún river valley and stream banks (our reference ecosystem) as environments with different hydrologic dynamics, soil types, and species composition.

According to their perception, only *I. vera*, *D. guianense* and *A. leucocalyx* (4% of the species) were abundant at riparian ecosystems (Fig. 3). Most species (70%) were considered of low to medium abundance and only two species (*B. mexicanum*, *E. mexicana*) were considered absent. There was no agreement about the abundance of five species (8%), namely *E. nigrita*, *J. dolichaula*, *L. platypus*, *M. glaberrima*, and *N. reticulata*. The relative species abundance denoted by farmers was not correlated (r_s = -0.0414, p = 0.8475) with the species abundance registered in the reference site surveys (Appendix S1).

Most species (41%) were used only for timber (i.e. fuel wood, fence posts, handles, boards and shelves), and five species (17%) had two use types besides timber (i.e. medicine and fodder). Only *B. alicastrum* had four use types: timber, food, medicine and fodder. Eleven species (38%) were reported as not used by local people.

Species producing seeds that were considered easy to collect represented 40% of the 30 species. Fifty three percent of the species were deemed easy to propagate with no pre-sowing treatment or only a simple mechanical scarification required (Appendix S2). However, we did not have suitable information about the appropriate introduction method for 33% of the species. Finally, 43% of the species attained a Tc value > 5, which could be a limitation when attempting to reintroduce native vegetation on disturbed sites.

Selection index and species selected

We calculated the SSI for the list of the 30 target woody species to restore disturbed riparian zones (Table 2). SSI was normally distributed with a mean (± SE) of 28.3±1.0, and ranged between 18 and 43. Less than half of the species (43%) scored an SSI higher than the mean. The species with the lowest SSI values were those with null SV (i.e. not used or accepted by the local farmers).

We found a significant negative correlation only between the natural regeneration potential (NRP) and the social value (SV; $r_s = -0.7036$; $p = 0.0008$), suggesting that those species that naturally established following secondary regrowth have lower social value among local farmers than those species that need being actively restored.

Discussion

Criteria for species selection

Natural dominance was the first criterion that we used for species selection. We targeted selection of woody species to initiate forest restoration projects. Although tropical riparian ecosystems contain other than woody species, these species can facilitate the establishment of other plants (Parrotta et al. 1997) when their architecture (e.g. leaf and canopy area) buffer harsh abiotic conditions (Meli & Dirzo 2013); by attracting seed dispersers when having fresh fruits (Slocum 2001); and by outcompeting (typically) shade intolerant grasses through reduction of their cover (Zimmerman et al. 2000). They also provide organic matter to the riparian soil and promote shore stabilization in the medium-term through their dense roots (Meli et al. 2013b). All these characteristics may be also considered as species selection criteria in forest restoration projects, but their inclusion will depend mainly on the ecological condition of the degraded ecosystem, and should be complemented with other criteria, as we showed in this work.

Once the restoration project has been established, it is necessary to consider a wider range of species to fill under-represented niches with other life-forms (e.g. herbs, palms, and ferns) and with rare, endangered, endemic and/or riparian-specialist species and thus to improve the structure and function of the riparian forest (Meli et al. 2013a) and promote higher diversity and functional redundancy (Brudvig & Mabry 2008). This will ensure the effectiveness of critical ecological processes that sustain ecosystems (SER 2004).

We used natural regeneration potential as the second criterion. The predictive potential of the abundance-size correlations for selecting target species from disturbed sites could be limited by the small sample size, and hence decrease as their age increases and its species composition starts to resemble that of the reference sites (Meli et al. 2013a). However, the typically low species abundance in highly diverse humid tropics makes it difficult to perform accurate correlations without higher statistical power.

Assessing some preferred ecological characteristics of target species is a different way to estimate the potential of establishment. For example, longevity, resistance to herbivores or physical damage, and tolerance to flooding in the case of riparian systems, could also be important features for assessing the potential of establishment. These features focus on the species responses to particular abiotic or biotic factors. Some of these ecological features are indirectly included in our habitat breadth score, since generalist species may have life-history and functional attributes to cope with biotic and abiotic environmental filters better than specialist species do (Young et al. 2005).

Young fallows such as those we surveyed to estimate the Natural Regeneration Potential are not always present in areas where restoration is being planned, but they are good sites to identify potential species for passive restoration purposes at the first stages of restoration efforts (Meli et al. 2013a). In subsequent stages of the restoration project, other sites such as older regeneration patches and other ecological species characteristics could be used.

Our target species list is useful to restore typical disturbed riparian forests in the studied region, including those human-disturbed sites that were abandoned recently (with minimal natural regeneration) or long ago (with substantial natural regeneration). Unlike Brudvig and Mabry (2008), we did not consider the species of the regional pool that were already established at the disturbed sites because they may not be the most suitable species in social or economic terms when degradation is not very severe, as it was the case in our study. The ability of such species to establish naturally in degraded areas is high, and therefore it may be more appropriate to use these species for restoration of severely degraded lands, such as mined sites (Sharma & Sunderraj 2005; Parrotta & Knowles 2001) or sites highly susceptible to erosion on steep slopes (dos Santos et al. 2008). Seed size and dispersal mechanism syndromes have also been used to understand which species might require active re-establishment and which might passively recolonize degraded sites (Pausas & Lavorel 2003). For example, regenerating species in disturbed sites are frequently those with small seeds, which are widely dispersed (Chazdon et al. 2007). We believe that regeneration indices (cf. dos Santos et al. 2008) are more accurate indicators of these two types of species. Although not all second-growth forests have recolonized degraded sites, and some species may be adapted to several forms of degradation (e.g. degraded soils, fires, and weed infestation), the regeneration potential is a good indicator of the potential use of the species for restoration purposes.

Habitat breadth was the third criterion. We found that half of the species were present in at least three geomorphological units, suggesting that these species could establish in the riparian forest as in other ecosystem types. Few species showed high habitat breadth for a particular unit, and only *A. leucocalyx* was present in the floodplain and should be re-established in riparian restoration sites in our case study. The occurrence of species at particular habitats is implicitly related to their recruitment niche and should be strongly linked to ecological restoration projects. Many species can persist as adults in a far broader niche than that into which they can successfully recruit (Young et al. 2005) because habitat associations of adults do not necessarily emerge at early life stages (Comita et al. 2007). Restoration activities may broaden the dispersal or recruitment niche through translocation of propagules and assisted establishment, and create non-regenerating populations by planting saplings where adults can develop but seeds fail to germinate or seedlings have limitations to establish themselves (Young et al. 2005).

Social value was the fourth criterion and a salient contribution of our proposed procedure for restoration. Our selected species were socially accepted or, at least, meant some appraisal or utility for local people, mostly for timber. However, selecting only socially valuable species may put in risk their establishment in the harsh conditions of a degraded site. Non-pioneer species are a typical case of this situation, but in the humid tropics they show high plasticity in their growth rates and often establish successfully when they are directly transplanted to open sites, even when these sites have not been previously colonized by pioneer species (Martínez-Garza et al. 2005). Monitoring field performance of these socially valuable species will be crucial in restoration projects.

Although it is not the case in our study, the number of use types could be much larger than abundance classes, making these two components not comparable. In such cases, averaging the normalized score in a single SV could be a way to obtain a single SV value. Another option could be using rank abundance and use types as separated values.

Interestingly, the species abundance denoted by local farmers (social information) was not correlated with the actual species abundance registered in the reference sites (ecological information; Appendix S1). At the same time, we found that those species that are naturally established following secondary regrowth had the lower social value among local people. This is an unusual outcome, considering that in other tropical regions the young, second-growth forests have high utilitarian as well as conservation value and will likely become important sources of timber and non-timber forest products (Chazdon & Coe 1999; Gavin 2009; Vœk 2004). This emphasizes the needs of further research on flora uses among local people, both in pristine and secondary riparian forest. The fact that people did not recognize the species by their abundance or ecological dominance does not mean that they do no actually use these species. Other criteria such as utility should be analyzed to evaluate the accuracy of our correlation to reflect real local uses in the region.

Local knowledge collected by interviews is important and useful to make local people pro-active participants at all stages of restoration practice (Blakesley et al. 2002b). Snapshots questionnaires may not reveal the species preferences of the local communities, but we believe they do reflect the farmer's perception as we infer from other previous participatory interviews that were conducted since our conservation project started several years ago.

Supply of ecosystem services (i.e. supporting, regulating, provisioning and cultural services) is directly related to human well-being (MEA 2005). Any woody species can supply more than one supporting and regulating service (e.g. habitat provision, carbon fixation, soil retention and many others). Thereby, the differences among these species are mostly related to their supply of provisioning or cultural services, and thus the use of species by local people could be a surrogate of such services.

Technical constraints for propagation and introduction of target species were the fifth criterion. This criterion considers ease of seed collection, germination and alternatives for introduction. Seed availability is indirectly included when valuing the ease to collect seeds of different sizes from fruits showing a variable dehiscence. However, species phenology and dioecism (seeds produced only by female trees) also affect seed availability, especially of mast-fruiting species. Further research about these characteristics of the 30 selected species would provide important information to estimate and value the entire spectrum of efforts to obtain enough seeds and will be considered as surrogate variables to score technical constraints in our riparian restoration project in the future.

While local people may be interested in propagating native species for their reintroduction in many restoration projects, this propagation may be time-consuming and expensive. Consequently, it is important to select species that are easily propagated since local communities cannot implement techniques that are costly or hazardous (e.g. use of acids for seed scarification). Research is needed to better understand the technical constraints to propagate and reintroduce native species, including species identification and studies of fruiting phenology, seed germination and nursery practice (Knowles & Parrotta 1995). Revegetation projects should emphasize the importance of this information. Lack of information underestimates the rating of some species but also guides future research on species propagation for restoration purposes. This highlights the “adaptability” of our procedure. Species could be selected on the basis of one or two criteria and, at the same time, they could generate useful information about the other criteria.

Seeds from species classified as difficult to propagate should not be collected in the first stages of the restoration project, as it would be more efficient and less costly to locate and transplant saplings from the forest (Knowles & Parrotta 1995). However, the conservation status of some target species may restrict this technique, because a threatened or endangered species may not bear additional reduction in its population through harvesting (Garibaldi & Tucker 2004). Also, reintroduction may be a successful strategy for overcoming dispersal limitations but may not reflect adult establishment (Turnbull et al. 2000); thus, the performance of transplanted species in the field should be included in our Tc index in future stages of the restoration project (Knowles & Parrotta 1995; Elliot et al. 2003).

Species Selection Index

The criteria used to constitute the SSI appear to be independent and complementary, as we found hardly any significant correlation among them. Thus, ideally they should be used simultaneously or at least in groups of two or three. We considered all five criteria to be equivalent when assembling the SSI. However, as we discussed above, when species establishment faces hard ecological limitations, ecological criteria could be more important than the technical or social ones (Sharma & Sunderraj 2005; dos Santos et al. 2008). Technical criteria could be considered most important when there are monetary or time constraints, whereas social criteria are essential and should be the prioritized when there is no consensus among ecological and social interests. Thus, priority ranking of species in Table 2 could be re-ordered following these criteria (e.g. ecological priority, social priority, and technical feasibility priority) in different restoration scenarios. The SSI average was near the median value, suggesting that species with high SSI were not frequent. At the same time, some species showed very low SSI due to lack of information, which highlights the dependence of the SSI on information availability.

The proposed procedure is useful to minimize costs and maximize efficiency in selecting species for forest restoration so that it can be attractive to different stakeholders. It can be applied as well to the screening and selection of woody species from a wide spectrum of other tropical and temperate regions. It is useful where trees are dominant, but its use would be limited in grasslands or other ecosystem types where species regeneration is difficult to estimate (Meli et al. 2013a). Further research is needed to select appropriate species to suit the specific ecological requirements in other ecosystem types.

Finally, the most appropriate methodology to select target species for restoration will strongly depend on the main objectives of any particular project. Other criteria could be considered in the selection of target species in other case studies, including adaptive capacity to different soils (Sharma & Sunderraj 2005), other social values (cf. Moreno-Cassasola & Paradowska 2009), or attributes such as dispersal syndromes (Sansevero et al. 2009). Technical constraints may be the most useful criterion in practical terms because these can increase the costs (time, labor, materials needed) of the restoration projects, but social criteria should be included in all restoration efforts (Garibaldi & Turner 2005).

Conclusions

We proposed a procedure to target species for forest restoration projects that leans on five criteria related to ecological, social and technical information. A major strength of this procedure is that the five criteria are independent and can be used separately in projects with different goals. Importantly, social information based on local perception is usually neglected in restoration projects. The high number of woody species found in the reference sites indicates that the regional species pool for riparian restoration is wide. To facilitate practical restoration, we identified a preliminary list of tree species that are most suitable for their reintroduction into degraded riparian zones in our study region and similar ecological and social settings (Brudvig & Mabry 2008).

A list of target species must be identified and used for the initial stages of restoration of ecosystems dominated by trees. However, the species selection criteria will depend on the main goals of the restoration project and on information availability. In human-dominated ecosystems or agricultural landscapes, prioritizing social and technical criteria to select species for restoration is crucial for restoration sustainability. Our procedure could be adapted to different social and ecological conditions and be enriched as new information is generated.

Acknowledgements

We thank C. Méndez and G. Jamangapé their field assistance. We are very grateful to M. González and J.A. Parrotta for comments on an early draft of this paper. R. Chazdon and an anonymous reviewer greatly improved the content and presentation of a previous version of this manuscript. A Rufford Small Grant for Nature Conservation was provided to P.M. (40.11.09). Pemex and the WWF-FCS Alliance supported Natura. JMRB thanks projects CGL2010-18312 (Spanish Ministry of Science and Education) and S2009AMB-1783 REMEDINAL-2 (Madrid Government).

Literature cited

Blakesley, D., Elliott, S., Kuarak, C., Navakitbumrung, P., Zangkum, C. & Anusarnsunthorn, V. 2002a. Propagating framework tree species to restore seasonal dry tropical forest: implications of seasonal seed dispersal and dormancy. *Forest Ecology and Management* 164:31-38.

Blakesley, D., Hardwick, K. & Elliott, S. 2002b. Research needs for restoring tropical forests in Southeast Asia for wildlife conservation: framework species selection and seed propagation. *New Forest* 24:165-174.

Brudvig, L. A. & Mabry, C. M., 2008. Trait-based filtering of the regional species pool to guide understory plant reintroductions in Midwestern Oak Savannas, U.S.A. *Restoration Ecology* 16:290-304.

Chazdon, R. L. & Coe, F. G. 1999. Ethnobotany of woody species in second-growth, old growth, and selectively logged forests of Northeastern Costa Rica. *Conservation Biology* 13:1312-1322.

Chazdon, R.L., Letcher, S. G., van Breugel, M., Martínez-Ramos, M., Bongers, F. & Finegan, B. 2007. Rates of change in tree communities of secondary Neotropical forests following major disturbances. *Philosophical Transactions of the Royal Society B* 362: 273-289

Comita, L. S., Condit, R. & Hubbell, S. P. 2007. Developmental changes in habitat associations of tropical trees. *Journal of Ecology* 95: 482-492.

Curtis, J. T. & McIntosh, R. P. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* 32:476-496.

De Vos, J. 2002. *Una tierra para sembrar sueños. Historia reciente de la Selva Lacandona 1950 – 2000*. Fondo de Cultura Económica, México.

dos Santos, R., Citadini-Zanette, V., Leal-Filho, S. & Hennies, W. T. 2008. Spontaneous vegetation on overburden piles in the coal basin of Santa Catarina, Brazil. *Restoration Ecology* 16:444-452.

Elliott, S., Navakitbumrunga, P., Kuaraka, C., Zangkuma, S., Anusarnsunthorna, V. & Blakesley, D. 2003. Selecting framework tree species for restoring seasonally dry tropical forests in northern Thailand based on field performance. *Forest Ecology and Management* 184:177-181.

Garibaldi, A. & Turner N., 2004. Cultural keystone species: implications for ecological conservation and restoration. *Ecology and Society* 9:1 [online] URL: http://www.ecologyandsociety.org/vol9/iss3/art1

Gavin, M. C. 2009. Conservation implications of rainforest use patterns: mature forests provide more resources but secondary forests supply more medicine. *Journal of Applied Ecology* 46:1275-1282.

Holl, K. D. 2007. Old field vegetation succession in the neotropics, Pp. 93-188 in Cramer, V., Hobbs, R. (eds.), *Old fields. Dynamics and restoration of abandoned farmland*. Island Press, Washington D.C.

Knowles, O. H. & Parrotta, J. A. 1995. Amazonian forest restoration: an innovative system for native species selection based on phonological data and field performance. Commonwealth *Forestry Review* 74:230-243.

Martínez-Garza, C., Peña, V., Ricker, M., Campos, A. & Howe, H. F. 2005. Restoring tropical biodiversity: leaf traits predict growth and survival of late-successional trees in early-successional environments. *Forest Ecology and Management* 217:365-379.

Meli, P. & Dirzo, R. 2013. Effects of grasses on sapling establishment and the role of transplanted saplings on the light environment of pastures: implications for tropical forest restoration. *Applied Vegetation Science* 16:296-304.

Meli, P., Martínez-Ramos, M. & Rey-Benayas, J. M. 2013a. Selecting species for passive and active riparian restoration in Southern Mexico. *Restoration Ecology* 21:163-165.

Meli, P., Rey Benayas, J.M, Carabias, J., Ruiz, L. & Martínez Ramos, M., 2013b. Restauración de los servicios ecosistémicos ribereños. Meta-análisis global y un estudio de caso en Chiapas, México. Pp. 39-58 in Lara, A., Laterra, P., Manson, R. & Barrantes, G. (eds.), *Servicios ecosistémicos hídricos en América Latina y el Caribe*. Red ProAgua - CYTED, Valdivia, Chile.

Mendoza, E. & Dirzo, R. 1999. Deforestation in Lacandonia (southeast Mexico): evidence for the declaration of the northernmost tropical hot-spot. *Biodiversity and Conservation* 8:1621-1641.

Millenium Ecosystem Assesment (MA) 2005. *Ecosystems and human well-being: a framework for assessment. Wetlands and water.* World Resources Institute, Washington D.C., USA.

Moreno-Cassasola, P. & Pardowska, K. 2009. Useful plants of tropical dry forest on the coastal dunes of the center of Veracruz State. *Madera y Bosques* 15:21-44.

Parrotta, J. A., Turnbull, J. W. & Jones, N. 1997. Catalyzing native forest regeneration on degraded tropical lands. *Forest Ecology and Management* 99:1-17.

Parrotta, J. A. & Knowles, O. H. 2001. Restoring tropical forests on bauxite mined lands: lessons from the Brazilian Amazon. *Ecological Engineering* 17:219-239.

Pausas, J.G. & Lavorel, S. 2003. A hierarchical deductive approach for functional types in disturbed ecosystems. *Journal of Vegetation Science* 14:409-416.

Sansevero, J. B. B., Prieto, P. V., Duarte de Moraes, L. F. & Pena-Rodrigues, P. J. F. 2009. Natural regeneration in plantations of native trees in lowland Brazilian Atlantic forest: community structure, diversity, and dispersal syndromes. *Restoration Ecology* 19:379-389.

Sharma, D. & Sunderraj, S. F. W. 2005. Species selection for improving disturbed habitats in Western India. *Current Science* 88:462-467.

Siebe, C., Martínez-Ramos, M., Segura-Warnholtz, G., Rodríguez- Velázquez, J. & Sánchez-Beltrán, S. 1995. Soil and vegetation patterns in the tropical rainforest at Chajul, Chiapas, Southeast Mexico. Pp. 40-58 in Simmorangkir, D. (ed.), *Proceedings of the International Congress on Soils of Tropical Forest Ecosystems, 3rd Conference on Forest Soils*. Mulawarman University Press, Samarinda, Indonesia.

Society for Ecological Restoration International Science & Policy Working Group (SER) 2004. The SER International Primer on Ecological Restoration. www.ser.org & Tucson: Society for Ecological Restoration International.

Slocum, M. 2001. How tree species differ as recruitment foci in a tropical pasture? *Ecology* 82:2547-2559.

Turnbull, L. A., Crawley, M. J. & Rees, M. 2000. Are plant populations seed-limited? A review of seed sowing experiments. *Oikos* 88:225-238.

Vœk, R. A. 2004. Disturbance pharmacopoeias: medicine and myth from the humid tropics. *Annals of the Association of American Geographers* 94:868-888.

Young, T. P., Petersen, D. A. & Clary, J. J. 2005. The ecology of restoration: historical links, emerging issues and unexplored realms. *Ecology Letters* 8:662-673.

Zimmerman, J. K., Pascarella, J. B. & Aide, M. A. 2000. Barriers to forest regeneration in an abandoned pasture in Puerto Rico. *Restoration Ecology* 8:350-360.

Supplementary material

Appendix S1 Participatory interviews with local communities and SV data.

Appendix S2 Tc methods and data.

Table S1 Species list in the reference sites.

Table S2 Species list in the disturbed sites.

Table S3 Data on I, NRP, and H.

Table 1. Species selection criteria included in the proposed procedure.

Criteria	Indicator	Information type
Natural dominance (D)	Importance Value Index (IVI_i)	Ecological
Natural regeneration potential (NRP)	Spearman rank correlation of abundance across size classes (r_s)	Ecological
Habitat breadth (H)	Occurrence in five geomorphological units	Ecological
Social value (SV)	Natural abundance in riparian systems and local use according to social perception	Social
Technical constraints (Tc)	Ease of propagation (seeds collection + germination + introduction alternatives)	Technical

Table 2. Species Selection Index values (SSI) for 30 woody species targeted for revegetation of riparian forest in Marqués de Comillas. The SSI integrates standardized values (categories of Z values, see text for details) of Natural dominance (D), Natural regeneration Potential (NRP), Habitat breadth (H), Social value (SV), and Technical constraints (Tc). (*) Species absent in disturbed forest and therefore considered to need active reintroduction (high NRP values).

Species	D	NRP	H	SV	Tc	SSI
Dialium guianense	8	10	9	9	7	43
Brosimum alicastrum	6	6	9	9	8	38
Brosimum costarricanum	6	10*	7	6	8	37
Ficus sp.	10	9	2	8	7	36
Cojoba arborea	10	6	4	5	7	32
Vochysia guatemalensis	5	7	7	8	5	32
Trophis racemosa	4	10*	6	6	6	32
Albizia leucocalyx	5	8	3	8	7	31
Ampelocera hottlei	6	3	7	6	9	31
Calophyllum brasiliense	5	6	7	6	7	31
Licania platypus	5	10*	6	6	4	31
Posoqueria latifolia	5	10*	6	5	5	31
Guarea glabra	5	3	7	6	8	29
Protium copal	7	3	9	6	3	28
Castilla elastica	5	3	6	6	7	27
Hirtella americana	4	4	7	5	7	27

Pouteria durlandii	5	5	7	6	4	27
Swartzia simplex	5	10*	3	5	4	27
Blepharidium mexicanum	4	5	6	4	7	26
Inga vera	4	5	3	9	5	26
Eugenia negrita	4	10*	7	0	5	26
Quararibea yunckerii	4	10*	3	6	3	26
Nectandra reticulata	5	10*	6	0	4	25
Miconia argentea	4	5	4	6	5	24
Jacaratia dolichaula	4	10*	6	0	4	24
Croton schiedeanus	5	2	6	5	5	23
Eugenia mexicana	5	6	4	0	5	20
Licaria capitata	4	10*	4	0	2	20
Nectandra sanguinea	5	10*	1	0	4	20
Miconia glaberrima	4	10*	1	0	3	18

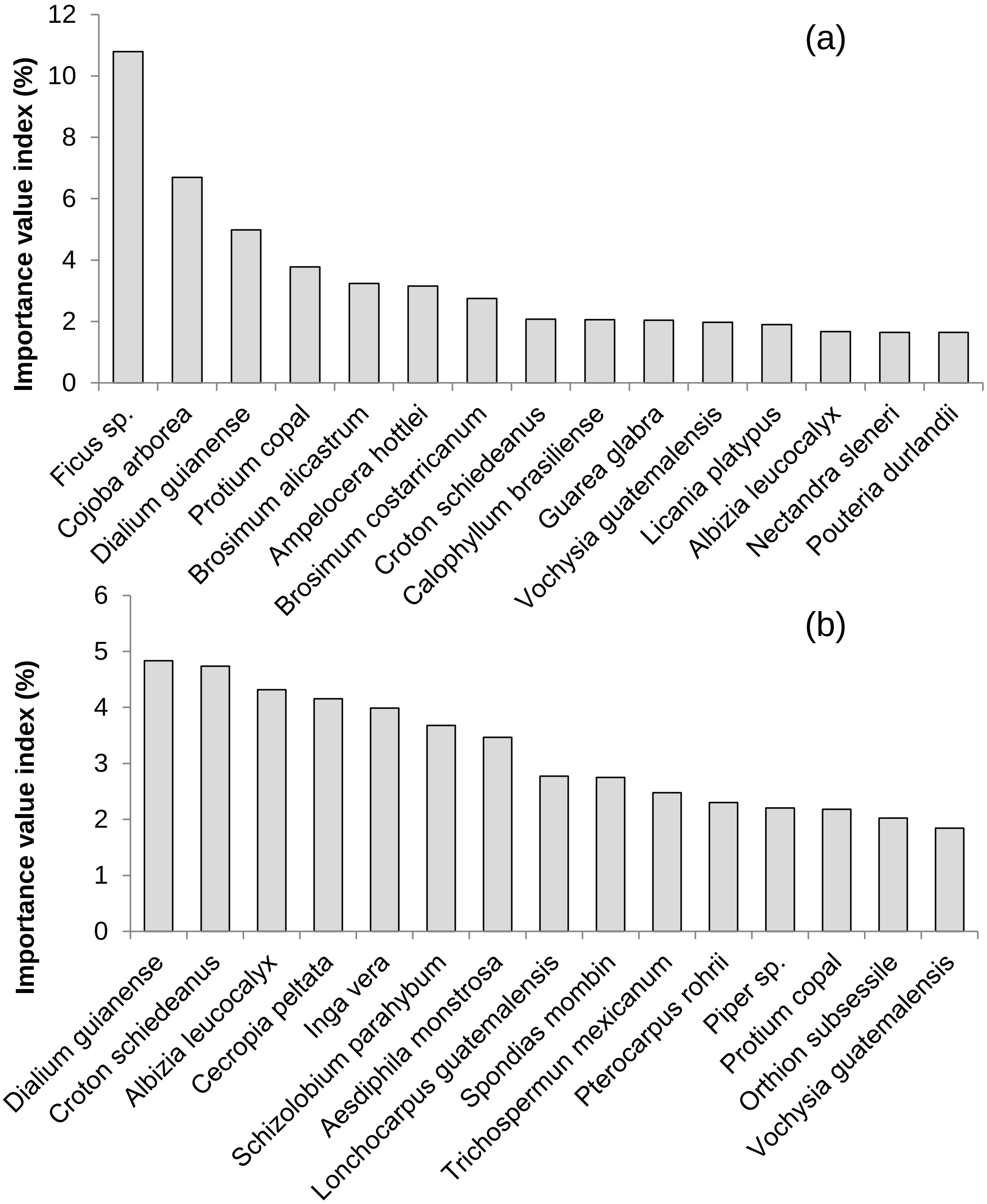

Fig. 1. Importance value index (IVI) of species accounting for >60% of total IVI in the six riparian reference forests (a) and in the five disturbed or secondary growth riparian forests (b).

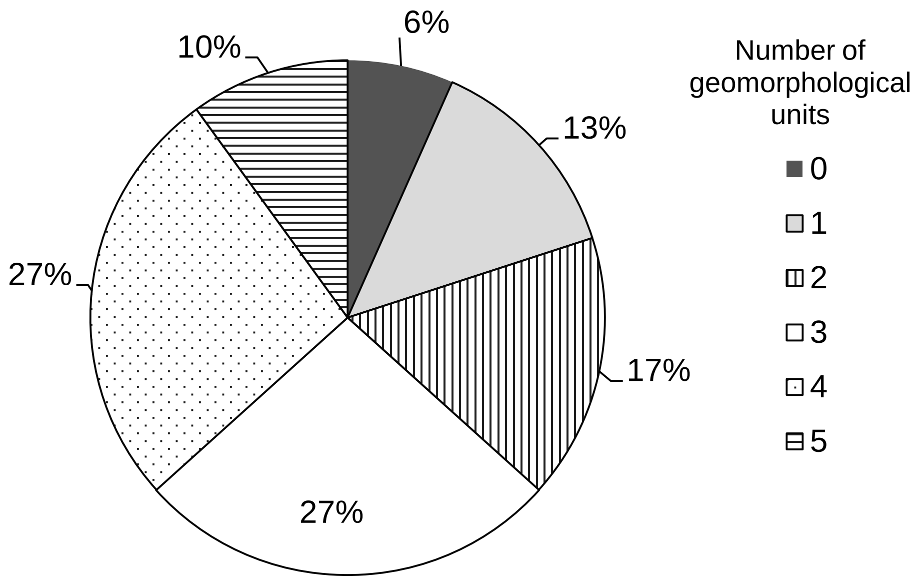

Fig. 2. Proportion of species out of the 30 studied native tree species occurring in different numbers of geomorphological units found in Marqués de Comillas.

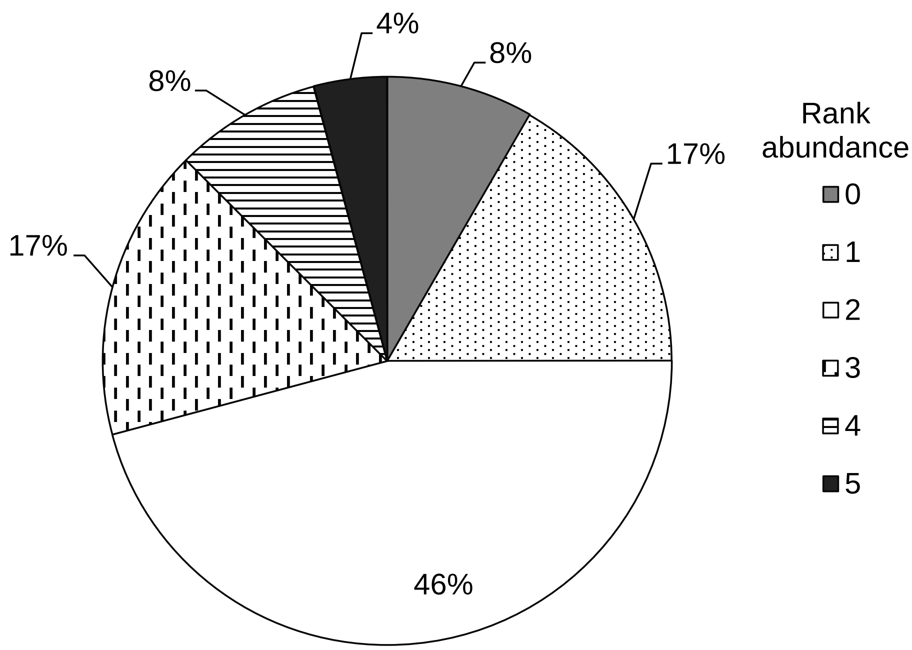

Fig. 3. Proportion of species out of the 30 studied native tree species occurring at six rank abundance categories according to local people perceptions found in Marqués de Comillas. See main text for details on rank abundance calculation.