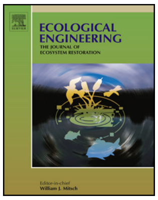
Ecological Engineering 103 (2017) 191–197

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Key plant indicators for monitoring areas undergoing restoration: A case study at the *Das Velhas* River, southeast Brazil

Vinícius Londe*, Hildeberto Caldas de Sousa, Alessandra R. Kozovits

Graduate Program in Ecology of Tropical Biomes, Federal University of Ouro Preto, campus Morro do Cruzeiro, s/n, Ouro Preto, Minas Gerais, 35400-000, Brazil

A R T I C L E   I N F O

Article history:
Received 17 November 2015
Received in revised form 10 March 2017
Accepted 1 April 2017
Available online 12 April 2017

Keywords:
Ecological restoration
Model selection
Monitoring indicators
Urban forests

A B S T R A C T

In restoration ecology, the search for key variables which allows an informative and concise diagnosis on areas undergoing restoration is still a challenge. Choosing which indicators to use is a fundamental decision when proposing monitoring of any restored area. Here, we have aimed to contribute with the selection of key indicators by identifying plant parameters that are useful to assess restored areas in using a 5-year-old rehabilitated riparian forest as a case study. Initially, we used 14 descriptors to assess the ecosystem attributes of structure, diversity and ecological processes, and then we conducted a model selection to identify variables that best explained the restoration success (defined as the richness of native tree species). Our final model contained six parameters: native tree species (the response variable), native and exotic species of other life forms, basal area, tree density, and canopy openness) and an adjusted R^2 of 92%. As the predictive model doesn't contain variables related to ecological processes, we included seedling recruitment or litterfall production to evaluate this attribute. The selected indicators evidenced that the tree layer has yet to develop and accumulate biomass, the forest has been enriched by species of other life forms (although many of them were exotic and invasive), and exotic tree and shrub species were dominating seedling recruitment. Such a scenario is likely to occur because the forest is located in an anthropogenic region, and highlights the importance of conserving remnant areas as propagule sources. We suggest some managing actions for the area, and conclude that not all measured indicators were necessary to facilitate good vision about the studied forest (because many had collinear responses), which may be important for directing other monitoring projects and save time and money.

1. Introduction

Ecological indicators play an important role in monitoring, evaluating and managing (Lin et al., 2009) both natural remnant ecosystems, or sites undergoing restoration. Ecological indicators are an attempt to avoid complicated measures and reduce ecosystem complexity, selecting simple parameters that can lead to satisfactory representation from a complex relationship (Müller and Lenz, 2006). In ecological restoration, indicators are generally used after project implementation, aiming to understand the current situation of the area, and to verify if some type of intervention is needed to accelerate the restoration process (Martins, 2011).

The discussion over the use of monitoring indicators has been increasing, mainly considering the requirements for establishing good parameters (Rodrigues and Gandolfi, 1998). In this sense, some studies have been trying to find indicators that better evaluate restoration success; for example, litterfall structure, species richness of plants, birds and ants (Ruiz-Jaén and Aide, 2005), canopy cover, basal area, and seedling recruitment (Suganuma and Durigan, 2015), etc. Even so, establishing key monitoring indicators is a challenge because implementing many parameters is expensive and does not always reach a proper/effective diagnosis of the area under restoration (Brancalion et al., 2012). Nevertheless, at the same time that monitoring indicators are desirable, it is hard to select which parameters to use due to (1) the complexity and individuality of each ecosystem and (2) because there are many indicators available.

Here, we address the problem of which indicators to use for monitoring areas undergoing restoration. We used a lot of plant indicators to evaluate a newly restored riparian forest in southeastern Brazil and then asked: Would it be necessary to use all the descriptors to make a good diagnosis of the area? Could some of them be removed? Which are collinear? Which indicators should be used? This study aimed to contribute to selecting key indicators for

---

* Corresponding author.
E-mail address: vlonde.ecologia@gmail.com (V. Londe).

http://dx.doi.org/10.1016/j.ecoleng.2017.04.012
0925-8574/

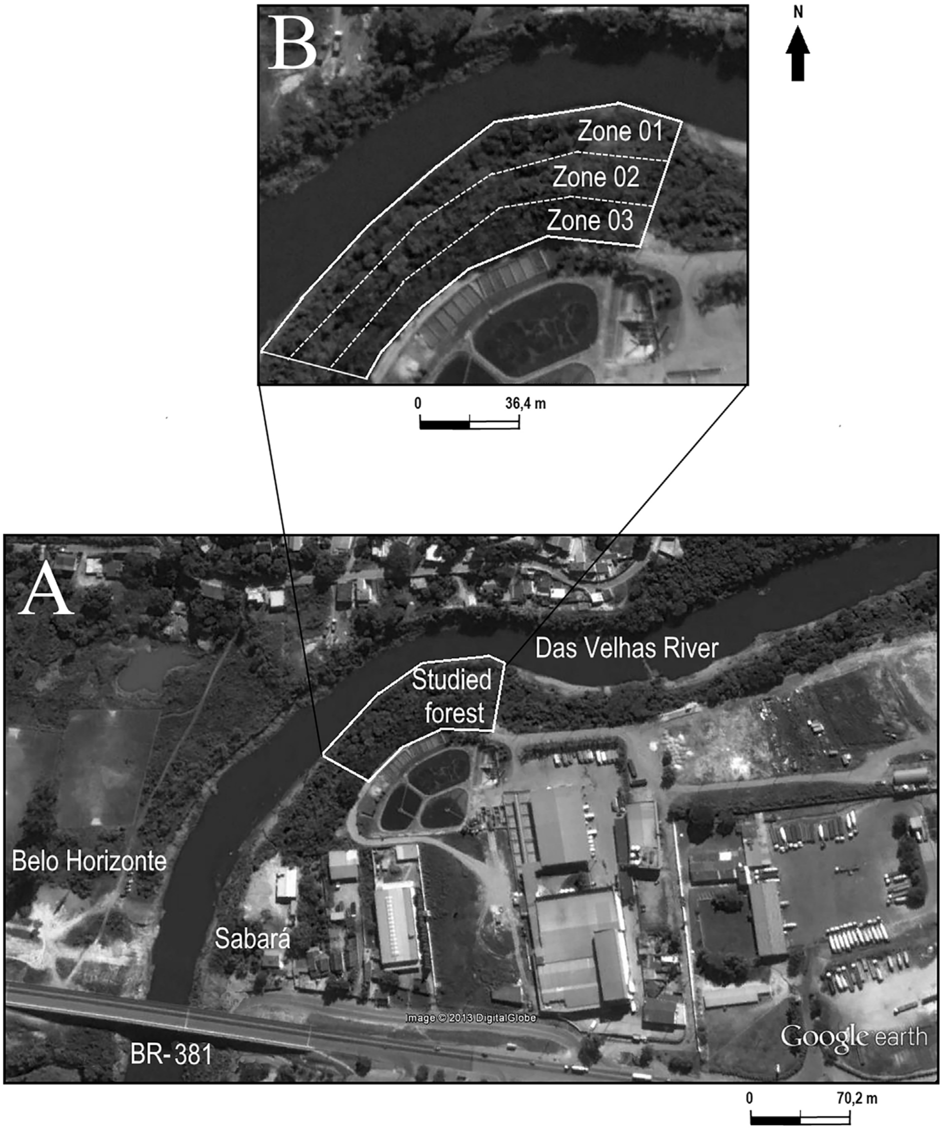


Fig. 1. Location of the studied area at *Das Velhas* River in Minas Gerais State, southeastern Brazil, detailing the anthropogenic region where the forest is located (A), and the three buffer zones where permanent parcels were installed (B). Font: Google Earth 2015, images date: 6/30/2012.

monitoring areas undergoing restoration by identifying the "best" plant attributes from a set of variables taken from a five-year-old riparian forest.

2. Material and methods

2.1. Studied area

We studied a forest at the *Das Velhas* River, a watercourse located in the middle of Minas Gerais State in southeastern Brazil and considered the largest tributary of the São Francisco River (Polignano et al., 2001). Its water sources are in the municipality of Ouro Preto, and its margins become highly urbanized after some kilometers. This is mainly into the metropolitan region of Belo Horizonte where the river is strongly degraded, although it is the main water course of the region (Polignano et al., 2001).

The studied forest is situated downstream of highway bridge BR-381 between the municipalities of Belo Horizonte and Sabará (Fig. 1A). The climate of the region is tropical with two well-defined seasons (a rainy season from November to April, and a dry season from May to October), with an average annual maximum temperature of 27.2 °C, a minimum temperature of 17.9 °C, and an average annual rainfall of 1549.8 mm (INMET, 2016–monthly data from 1986 to 2016, except 1987).

The forest belongs to a Program called the *Manuelzão* Project for the revitalization of the *Das Velhas* River, which is being developed by the Federal University of Minas Gerais (UFMG). The studied area has a slaughterhouse and a residential district around it, and in 2007 due to problems caused by deforestation, siltation and erosion of the riverbanks, a flooded forest (among other actions) of approximately 0.5 ha was implanted in the area aiming to stop soil erosion and reduce risks to nearby residents (Fig. 1A).

First, the area was cleared. Then some physical barriers made of rocks and wood were installed along the watercourse and the ground was leveled, keeping an elevational difference from the watercourse to 50 m at the margin. The restoration method was by total planting (2 × 2 m) and a model of buffer zones based on Schultz et al. (2004) was used to create a riparian forest. In this model three zones are implanted, each one with different species composition and function, namely: zone 1 – an unmanaged area adjacent to the

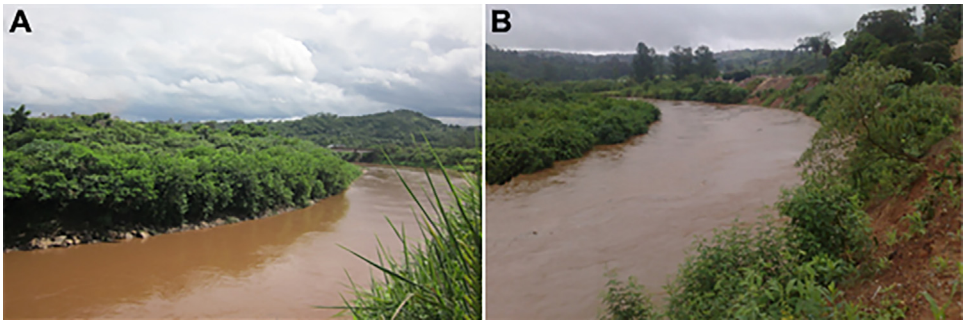


Fig. 2. Photos of the studied area at *Das Velhas* River in southeastern Brazil taken in the dry (A) and rainy (B) seasons. The studied area becomes partially flooded due an elevational difference. Images kindly provided by Dr. Maria Rita S. Muzzi, Federal University of Minas Gerais.

Table 1
List of species used in the rehabilitation project in a riparian forest at *Das Velhas* River, Sabará, Minas Gerais State, Brazil. Modified from Londe et al. (2017).

Planting zones	Planted species	
01	*Croton urucurana* Baill.†	*Psidium guajava* L.*
	Erythrina verna Vell.†	*Psidium rufum* Mart. ex DC.†
	Eugenia uniflora L.†	*Miconia* sp.†
	Inga edulis Mart.†	*Morus nigra* L.§
	Inga vera Willd.†	*Myrsine* sp.†
02	*Anadenanthera peregrina* (L.) Speg.†	*Inga edulis* Mart.†
	Centrolobium tomentosum Guillem. ex Benth.†	*Luehea grandiflora* Mart. & Zucc.†
	Handroanthus impetiginosus (Mart. ex DC.) Mattos†	*Piptadenia gonoacantha* (Mart.) J.F.Macbr.†
	Hymenaea courbanil L.†	
03	*Acrocomia aculeata* (Jacq.) Lodd. ex Mart.†	*Mimosa bimucronata* (DC.) Kuntze†
	Cecropia sp.†	*Peltophorum dubium* (Spreng.) Taub.†
	Ceiba speciosa (A.St.-Hil.) Ravenna†	*Samanea tubulosa* (Benth.) Barneby & J.W.Grimes‡
	Machaerium hirtum (Vell.) Stellfeld†	*Sterculia* sp.†
	Machaerium sp.†	
Herbs (general area)	*Arachis pintoi* Krapov. & W.C.Greg.†	*Piper umbelattum* L.†
	Helianthus annuus L.§	*Stylosanthes guianensis* (Aubl.) Sw.†
	Miconia sp.†	*Tradescantia* sp.†

Legend: *Naturalized/†Native species of Minas Gerais State/‡Native from Brazil but not of Minas Gerais/§Exotic. Species classified according the List of Species of the Brazilian Flora (2016).

water body for tree preservation (10 m width); zone 2 – an intermediary managed zone with woody species (21 m); and zone 3 – a buffer area for soil management farther from the watercourse (15 m) (Fig. 1B). Approximately 480 seedlings of 23 native shrub and tree species, two exotic fruit trees and six herbs were planted in the total area (±0.5 ha) (Table 1). This area becomes partially flooded during the rainy season due to the elevational difference, as shown in Fig. 2. The forest has flooded twice through the period of study; once in December and once in January.

2.2. Experimental design and statistical procedure

In order to know the current situation of the rehabilitated forest, we randomly installed 15 permanent parcels of 100 m^2 each (10 × 10 m) into the area with five parcels per planting zone (Fig. 1B), and monthly visits were conducted for data collection from November 2011 to October 2012. In total, we measured 14 indicators (Fig. 3A), and they were classified according to three ecosystem attributes (Ruiz-Jaén and Mitchell Aide, 2005). We chose these indicators because they are relatively simple to measure and commonly used to monitor areas under restoration in Brazil (Martins, 2011) and other countries (Ruiz-Jaén and Aide, 2005). For a detailed description of how each indicator was sampled, please see Supplementary material A.

We then conducted a model selection to identify the key indicators for the studied area. First, we used Anderson-Darling tests to assess the normality of data (only the data of seedling density was log-transformed), and then we constructed a linear model with the additive combination of all (14) indicators, using the native tree species richness as the response variable. This variable is generally used as a proxy for restoration success because it reflects the establishment of the planted saplings (Young, 2000).

We submitted the full model to stepwise regression using an α (alpha) = 0.15 as the cut-off value to find the best subset of predictor variables that explained the collected data (Zuur et al., 2007). We also performed variance inflation factor (VIF) analysis to verify multicollinearity between predictor variables, and those with collinearity (VIF > 3) were removed from the model. We chose the model with the highest adjusted R^2 in which *P*-values were significant for all variables and having no collinearity between them as the most parsimonious (Zuur et al., 2007; Logan 2010). Finally, we created scatterplots with multiple regressions to explore relations between the selected variables (Logan, 2010). We ran all statistical procedures in Minitab 17.1.0 software (Minitab, 2013).

3. Results

3.1. Vegetation structure

In total, we registered 219 live trees and one dead tree with a mean height (± standard deviation) of 5.4 ± 1.8 m, and mean DBH 7.3 ± 4.4 cm. Tree density and total basal area were 470.09 ind./ha^{-1} and 12.6 m^2/ha^{-1}, respectively. Regarding seedling density, we recorded a mean density of 0.13 ind./m^2, however most of them were from exotic and invasive species (mainly *Leucaena leucocephala* and *Ricinus communis*).

Analyzes of hemispherical photographs demonstrated that mean canopy openness in the rainy season was 23.7 ± 4.7% and LAI

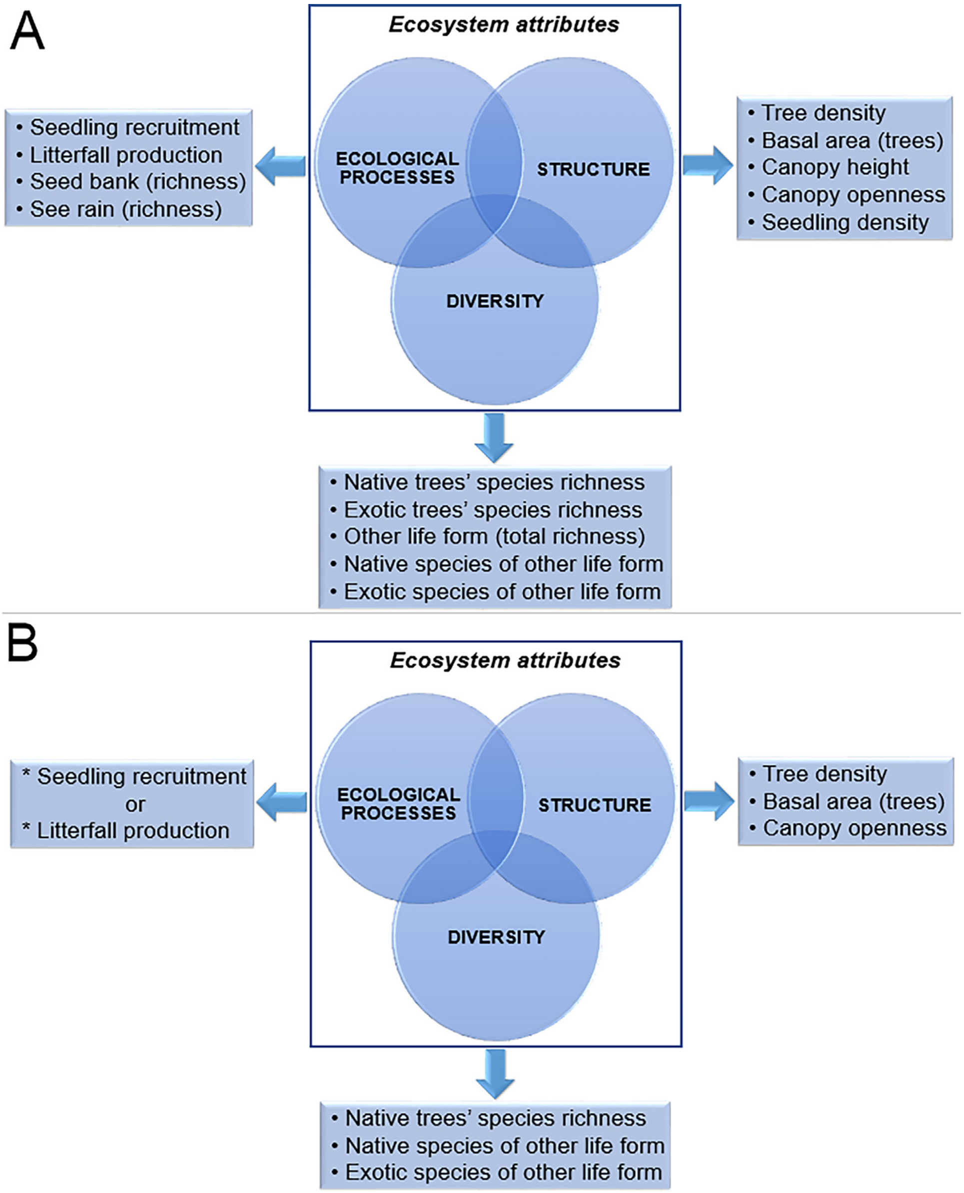


Fig. 3. Diagram illustrating the set of plant indicators, distributed according three ecosystem attributes, used to evaluate a five-year-old riparian forest at *Das Velhas* River in southeastern Brazil (A). Through model selection the number of indicators was reduced to six and we suggest to use at least one more to assess the ecological processes (B). These indicators might be considered the "best" parameters to assess the restored forest.

was 2 ± 0.4, whereas in the dry season canopy openness increased to 38.8 ± 7.7% and LAI decreased to 1.4 ± 0.4. The mean of the two seasons was 31.3 ± 3.7% for canopy openness, and 1.7 ± 0.2 for LAI.

3.2. Diversity

We registered 27 tree species; 18 of them were identified until species level, two until genera, and nine couldn't be identified. Of the total identified tree species, 13 were native and five were exotic. Moreover, we found a total of 84 species of other life forms: four shrubs, 73 herbs, six lianas, and one parasite. Of these species, 43 were native and 18 were exotic (Supplementary material B).

In total, we classified 65% of the identified species as weeds (Supplementary material B). Between exotic species, some such as the trees *Leucaena leucocephala* and *Tecoma stans*, and the herbs *Megathyrsus maximus* and *Cenchrus purpureus* are highlighted due to their invasion potential.

3.3. Ecological processes

We estimated a total annual litterfall production of 8.4 Mg ha^{-1} yr^{-1} with two productivity peaks: one in the end of the rainy season (April) and another more pronounced in the middle of the dry season (August). Litterfall was composed of 65% leaves, 17% twigs, 16% reproductive structures, and 2% of other components.

Regarding seedling recruitment, we recorded 192 individuals, but they belonged to only 13 species. There was a dominance of exotic and invasive species. For instance, *Leucaena leucocephala* seedlings represented 41% of the total and *Ricinus communis* represented 37.5%. Among native species, only *Croton urucurana* had a higher contribution to recruitment (7.8%), but with low frequency (only occurring in two plots).

We registered 87 species in the seed bank experiments, and 88.5% of them were herbs, 8% trees, and 3.5% lianas. Among identified species (n = 68), 53% were native and 47% were exotic, but

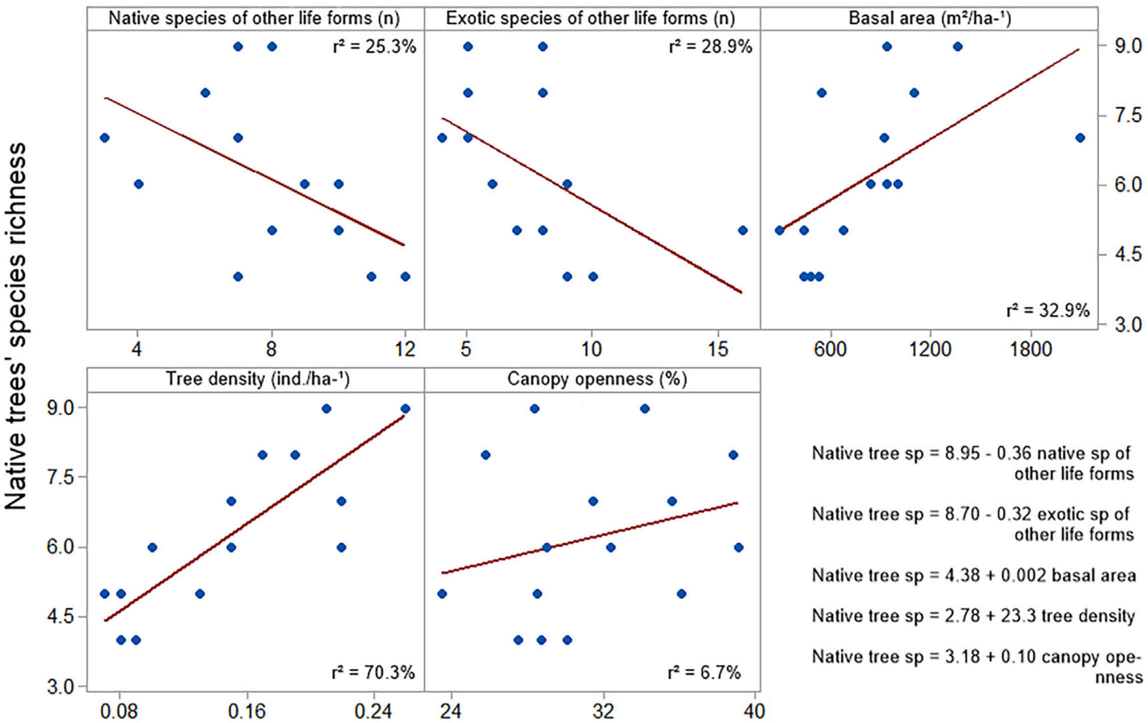


Fig. 4. Graphs and equations resulting the regressions done between native trees' species richness and other indicators picked out in the model selection. Data obtained in the assessment of a five-year-old riparian forest at *Das Velhas* River in southeastern Brazil.

53% were classified as weeds. Species common to three seed banks represented 19.5% of the total species richness, with only three tree species; *Croton urucurana*, *Mimosa bimucronata* (natives), and *Tecoma stans* (exotic).

We collected 553.10 g of seeds in the seed rain experiment, where January and July were the most productive months (133 g and 94 g, respectively). In total, 642 plants emerged in the boxes and represented 10 species: four indigenous (*Begonia* sp., *Croton urucurana*, *Ipomoea cairica*, and *Mimosa bimucronata*), five exotic (*Leucaena leucocephala*, *Melia azedarach*, *Mucuna pruriens*, *Ricinus communis*, and *Tecoma stans*), and one undetermined. Regarding life forms, half of the species were trees and dominated the samples; only *R. communis* was classified as a weed.

3.4. Selection of key-indicators

In total, eight variables were removed from the model selection because they presented multicollinearity: viz, canopy height, seedling density, exotic tree species richness, total species richness of other life forms, seedling recruitment, litterfall production, seed bank and seed rain. Thus, our final model contained six variables (one response and five predictors) (Fig. 3B), and the equation is as follows: Native tree species = 6.51 – 0.387 Native species of other life forms + 0.234 Exotic species of other life forms – 0.001 Basal area + 36.71 Tree density – 0.122 Canopy openness. This predictive model had an adjusted R^2 of 92.14%, and there was a positive relation between native tree species with basal area, tree density and canopy openness; and a negative relation with native and exotic species of other life forms (Fig. 4). We included two possible indicators to evaluate ecological processes, as the final model did not contain any variable related to this attribute (Fig. 3B).

4. Discussion

We started with a total of 14 indicators and selected seven (considering only one of the two related to ecological processes) as good predictors of restoration success. Regarding structure indicators, canopy openness showed that the forest had good shade cover (about 70%). This is a value used as reference for canopy structuring, for example in evaluating forests under restoration in the Atlantic Forest in Brazil (PACTO, 2013). This indicator has significant effect on the understory, influences regeneration dynamics and acts as a biodiversity filter on the plants which attempt to regenerate under it (Gandolfi et al., 2007). In our study, the (weak) positive relation between species richness of native trees and canopy openness might be a result of species identity; maybe the planted trees do not produce large crowns, so canopy openness does not decrease even when increasing species richness.

With respect to tree density, it may be a useful indicator of how many planted individuals had success and established in the area, at least in the first years after planting. In our case study, about 480 ind./ha^{-1} were planted in 2007 and currently 470 ind./ha^{-1} are registered, indicating that some planted individuals died during this period. In fact, a floristic and phytosociological analysis showed that some species disappeared from the area and others were found with few individuals (Londe et al., 2017). The other selected indicator of structure (basal area) is an important indicator of biomass accumulation (Chiba, 1998), and our studied forest had a total basal area similar to another three-year-old riparian forest under restoration at the Medium Paranapanema Valley, São Paulo, Brazil (Melo and de Durigan, 2007). Both indicators may show evidence that the studied forest has yet to structurally develop, and point out that species richness might positively influence the density and basal area.

The diversity indicators revealed vital information about the forest's species composition. Using the response indicator (native trees' species richness), we could verify which planted species have settled and which have not settled in the area, and possibly make practical recommendations for future restoration projects in areas that have a similar species composition. Plants that have established (for example *Piptadenia gonoacantha* and *Erythina speciosa)* have features which permitted them to make it through local ecological filters (floods and interspecific competition, for instance) and survive. On the other hand, species such as *Acronomia aculeata* and *Hymenaea courbaril*, although being recommended for recovering riparian forests (Martins, 2011), were not successful in colonizing the area.

Interestingly, the total species richness of other life forms was not selected in the final model, but the richness of native and exotic species were separated. This might reinforce that species classification regarding their origin is a relevant issue when working with floristic composition. Represented mainly by herbs, the richness of native and exotic species of other life forms evidenced that the forest has been enriched by species of external sources, however there were many exotic and weed species because the site is located in an urban region. Even some species among the native ones are considered invasive and aggressive, for example *Ageratum conyzoides* and *Solanum americanum* (Lorenzi, 2008). It has been recognized that riparian forests connected with open areas are highly susceptible to colonization by exotic and invasive species, and others of low conservation interest (Bowers and Boutin, 2008). Moreover, these findings highlight the importance in conserving remnant ecosystems in order to contribute to native species propagating areas under restoration.

There are many problems related to the presence and abundance of exotic and invasive species (suppression of native vegetation, increasing the risk of fires (mainly grasses), for example) and they might compromise restoration success (Lamb and Gilmour, 2003). Although it is difficult to affirm that there is a cause-and-effect function, this may be an explanation for the negative relation between the increase in species richness of other life forms and the decrease in the number of native tree species.

The richness of exotic trees was not included in the final model; however, this information is very useful for making management decisions. Classifying trees as native or exotic is an easy task once they have been collected and identified, and such classification is recommended. We also suggest that at least one indicator of ecological processes should be evaluated to give a broader vision about the forest under restoration. In this sense, seedling recruitment is a good option because this process is responsible for adding new individuals into a community, thus affecting its composition and dynamics (Ribbens et al., 1994), and it has been highlighted as a key-indicator as it expresses the final product of the seed and seedling banks, seed rain, and use of the restored area by frugivorous organisms (Brancalion et al., 2012).

Some native species in the studied area were already recruiting seedlings (*Croton urucurana* and *Inga edulis*, for instance), but exotic species were dominating (especially *Leucaena leucocephala*, *Ricinus communis* and *Tecoma stans*). This finding must be interpreted as a negative point and alerts the need for management actions (Martins, 2011). In other cases, seedling recruitment may be low or even absent (mainly in the first years after restoration), and indicates that few planted species are reproducing or external sources are contributing little to recruiting new individuals. On the other hand, if the productivity and return of other ecological functions in the restored area are required, quantifying litterfall production is a better way (Londe et al., 2016). However, it may require more time and sampling effort than seedling recruitment.

5. Conclusion

Not all indicators evaluated in our study were necessary to make a proper diagnosis on the studied forest. We verified that some of them could be removed from the analyses because they presented multicollinearity. Thus, in order to evaluate the area under restoration we could have only used the indicators contained in the final model derived from the model selection (tree density, basal area, canopy openness, native tree species, native species of other life forms, and exotic species of other life forms), plus one we designated to assess the ecological processes (seedling recruitment or litterfall production).

In using these variables, we noticed that the studied forest has yet to structurally develop, some planted species did not survive in the early years of restoration, and exotic and invasive species were colonizing the area, including some tree and shrub species which were recruiting new individuals. Such a scenario is likely to result from the area location (which is embedded in an urban matrix), and highlights the need for some management actions. These might include controlling exotic species either by cutting the plants or by applying local herbicides, enriching the forest with native species, perhaps by nucleation techniques to improve successional processes (Reis et al., 2010), and, if possible, increasing the extension of the restored area.

We believe that selected indicators are useful for monitoring other areas under restoration (taking into account the objectives of the restoration project), feasibly saving time and money because it is not necessary to use a lot of complicated parameters, and they still provide a strong basis for making management decisions.

Acknowledgments

We are grateful to Dr. Mª Rita S. Muzzi, at the Federal University of Minas Gerais, for allowing the development of this study in her restored area; CAPES (Coordination for the improvement of high personnel) for the master's scholarship of the first author; PROPP (Department of research and post-graduation); and the Department of Transport of the Federal University of Ouro Preto (UFOP) for their logistical and financial support.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2017.04.012.

References

Bowers, K., Boutin, C., 2008. Evaluating the relationship between floristic quality and measures of plant biodiversity along stream bank habitats. Ecol. Indic. 8, 466–475, http://dx.doi.org/10.1016/j.ecolind.2007.05.001.

Brancalion, P.H.S., Viani, R.A.G., Rodrigues, R.R., Gandolfi, S., 2012. Avaliação e monitoramento de áreas em processo de restauração. In: Martins, S.V. (Ed.), Restauração ecológica de ecossistemas degradados. Editora UFV, Viçosa, pp. 262–293.

Chiba, Y., 1998. Architectural analysis of relationship between biomass and basal area based on pipe model theory. Ecol. Modell. 108, 219–225, http://dx.doi.org/10.1016/S0304-3800(98)00030-1.

Gandolfi, S., Joly, C.A., Rodrigues, R.R., 2007. Permeability – impermeability: canopy trees as biodiversity filters. Sci. Agric. 64, 433–438, http://dx.doi.org/10.1590/S0103-90162007000400015.

INMET – Instituto Nacional de Meteorologia, 2016. BDMEP–Banco de Dados Meteorológicos para Ensino e Pesquisa (Accessed 15 December 2016) http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep.

Lamb, D., Gilmour, D., 2003. Rehabilitation and Restoration of Degraded Forests. IUCN, WWF, Gland, Switzeland and Cambridge, UK.

Lin, T., Lin, J., Cui, S., Cameron, S., 2009. Using a network framework to quantitatively select ecological indicators. Ecol. Indic. 9, 1114–1120, http://dx.doi.org/10.1016/j.ecolind.2008.12.009.

List of Species of the Brazilian Flora, 2016. Rio de Janeiro Botanical Garden (Accessed 16 September 2016) http://www.reflora.jbrj.gov.br.

Logan, M., 2010. Biostatistical Design and Analysis Using R: a Practical Guide. Wiley-Blackwell, Singapore, http://dx.doi.org/10.1002/9781444319620.

Londe, V., De Sousa, H.C., Kozovits, A.R., 2016. Litterfall as an indicator of productivity and recovery of ecological functions in a rehabilitated riparian forest at das velhas river southeast brazil. Trop. Ecol. 57, 355–360.

Londe, V., Sousa, H.C., Kozovits, A.R., 2017. Exotic and invasive species compromise the seed bank and seed. J. For. Res., 1–8, http://dx.doi.org/10.1007/s11676-017-0370-2.

Lorenzi, H., 2008. Plantas daninhas do Brasil: terrestres, aquáticas, parasitas e tóxicas, fourth ed. Instituto Plantarum, Nova Odessa.

Müller, F., Lenz, R., 2006. Ecological indicators: theoretical fundamentals of consistent applications in environmental management. Ecol. Indic. 6, 1–5, http://dx.doi.org/10.1016/j.ecolind.2005.08.001.

Martins, S.V., 2011. Recuperação de matas ciliares, second ed. Aprenda Fácil, Viçosa.

Melo, C.A.G., de Durigan, G., 2007. Evolução estrutural de reflorestamentos de restauração de matas ciliares no Médio Vale do Paranapanema Structural evolution of planted riparian forests in the Medium Paranapanema Valley, SP, Brazil. Sci. For. 101, 101–111.

Minitab 17 Statistical Software, 2013. Computer Software. State College, PA: Minitab, Inc www.minitab.com.

PACTO-Pacto pela Resturação da Mata Atlântica, 2013. Protocolo de monitoramento para programas e projetos de restauração florestal. http://www.pactomataatlantica.org.br. (Accessed 5 January 2017).

Polignano, M.V., Polignano, A.H., Lisboa, A.L., 2001. Uma viagem ao projeto Manuelzão e à bacia do Rio das Velhas: Manuelzão vai à escola. Coleção Revitalizar, Belo Horizonte.

Reis, A., Bechara, F.C., Tres, D.R., 2010. Nucleation in tropical ecological restoration. Sci. Agric. 67, 244–250, http://dx.doi.org/10.1590/S0103-90162010000200018.

Ribbens, E., Silander, J.A., Pacala, S.W., 1994. Seedling recruitment in forests: calibrating models to predict patterns of tree seedling dispersion. Ecology 75, 1794–1806, http://dx.doi.org/10.2307/1939638.

Rodrigues, R.R., Gandolfi, S., 1998 Restauração de florestas tropicais: subsídios para uma definição metodológica e indicadores de avaliação e monitoramento, in: Dias, L.E., Mello, J.W.V. (Eds.). Recuperação de áreas degradadas. Editora UFV, Viçosa, pp. 203–215.

Ruiz-Jaén, M.C., Aide, T.M., 2005. Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. For. Ecol. Manage. 218, 159–173, http://dx.doi.org/10.1016/j.foreco.2005.07.008.

Ruiz-Jaén, M.C., Mitchell Aide, T., 2005. Restoration success: how is it being measured? Restor. Ecol. 13, 569–577, http://dx.doi.org/10.1111/j.1526-100X.2005.00072.x.

Schultz, R.C., Isenhart, T.M., Simpkins, W.W., Colleti, J.P., 2004. Riparian forest buffers in agroecoystems–lessons learned from the Bear Creek Watershed, central Iowa, USA. Agrofor. Syst. 61, 35–50, http://dx.doi.org/10.1111/j.2345-100X.2005.00072.x.

Suganuma, M.S., Durigan, G., 2015. Indicators of restoration success in riparian tropical forests using multiple reference ecosystems. Restor. Ecol. 23, 238–251, http://dx.doi.org/10.1111/rec.12168.

Young, T.P., 2000. Restoration ecology and conservation biology. Biol. Conserv. 92, 73–83, http://dx.doi.org/10.1016/S0006-3207(99)00057-9.

Zuur, A., Ieno, E.M., Smith, G.M., 2007. Analysing ecological data. In: Statistic for Biology and Health Series. Springer, New York.