

Chapter 26

Multicriteria Site Prioritization for Land Rehabilitation in the Guapi-Macacu Watershed, Rio de Janeiro



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Abstract Progressing land degradation is of increasing global concern because it deteriorates essential ecosystem features, functions, and services as observed in our study area in the highly fragmented Mata Atlântica biome, RJ, Brazil. The prioritization of sites for land rehabilitation is a frequent task for environmental managers and essential to develop urgently needed public policies. Hence, we present a GIS-based tool based on ecological principles for the selection of reforestation sites by integrating data on pasture degradation and landscape fragmentation. Thereby, the prioritized areas do not only represent opportunities for increasing forest cover and enhancing forest connectivity but also for reducing the area of degraded pastures. From our perspective, the inclusion of spatial information on degraded pastures is essential, since many of these areas have lost important ecological and economic function and should thus be prioritized for intervention. Data on degraded pastures and forest cover used in this study are derived from high- and medium-resolution satellite imagery. Other spatial data are derived from a digital elevation model

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(DEM) with 20 m resolution. The multicriteria analysis for the data integration was conducted using ESRI ArcGIS and the open-source software ILWIS.

Keywords Mata Atlântica · Spatial multicriteria evaluation · Site prioritization · ILWIS · Rehabilitation

26.1 Introduction

Land degradation is of major global concern, especially in the context of climate change and food security. The ecological consequences of land degradation are diverse and lead among others to biodiversity loss, reduction of carbon storage capacities, and fertile soils as well as alteration of the water cycle. Rehabilitation of the land aiming at restoring important ecosystem services is therefore needed to counteract the negative consequences of degradation (Gurr et al. 2014). Hence, site selection for rehabilitation is a common task in decision-making in landscape planning for many purposes, e.g., environmental conservation plans and payments for ecosystem services programs (Malczewski 2006; Rodrigues et al. 2009; Orsi et al. 2011; Gjorup et al. 2016). The prioritization always depends on the selected criteria and on the preferences of the decision-maker, namely, the weights they decide to give to the single-selected criteria (Malczewski 2006).

In pasture-dominated landscapes, the as-is status of the pastures is to our understanding the key for proper selection of reforestation sites, in order to optimize the impacts of reforestation projects. Reforestation may thus not only aim at gains in forest area but also at improving connectivity and core areas as well as reducing the area of degraded pastures and soil loss and increasing the carbon storage. Hence, we consider the degradation status of the land for the selection of priority areas as an indispensable criterion for site selection. Based on this, the objectives of our study are (i) to offer a GIS-based methodology to identify rehabilitation sites of high priority that fulfill the defined criteria, aiming at an ecological optimization of the landscape through proper reforestation planning and (ii) to provide a map indicating the prioritized areas under ecological and legal principles.

26.2 Methods

26.2.1 Study Area

Our study area is located within the Guapi-Macacu watershed in the northwest of the metropolis of Rio de Janeiro. Formerly a forest-dominated ecosystem, the Guapi-Macacu watershed suffered from wood extraction and successive cycles of agricultural occupation since the sixteenth century (Dean 1997; Cabral 2004; Carneiro et al. 2012; Nehren et al. 2013). Today, the area is characterized by a high

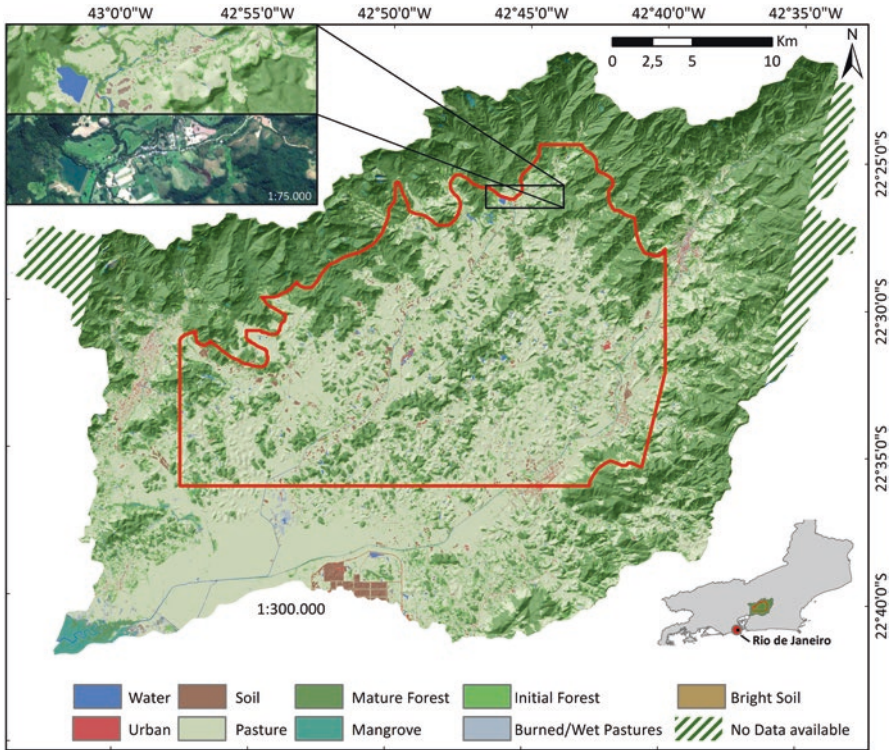


Fig. 26.1 Overview of the Guapi-Macacu watershed with the study area marked by a red polygon. Strong forest fragmentation is clearly visible in the lowlands of the watershed. The underlying land cover map (2011) with 5 m resolution was created based on RapidEye data with SWIR bands of SPOT 5 and Landsat 5 TM using RandomForests classifier in R

degree of forest fragmentation and pastures being the mainland use type. However, due to inadequate management practices, most of them show light to strong signs of degradation (Fidalgo et al. 2014). Besides, many of the forest fragments are extremely small or have such an irregular shape that if assuming an edge effect of 100 m (Ribeiro et al. 2009), they do not even contain a core area. The vicinity, however, to one of the major and highly diverse remaining forest remnants of the biodiversity hotspot, Mata Atlântica protected by the Três Picos State Park, emphasizes the importance for conservation of the many small forest fragments located within this watershed as stepping stones (Nehren 2008; Nehren et al. 2013).

The irregular shape of the study area is due to the data availability. The area's size is of approx. 460 km² and encompasses the main part of the lowland of the Guapi-Macacu watershed, where most of the small-sized forest fragments are located (Fig. 26.1).

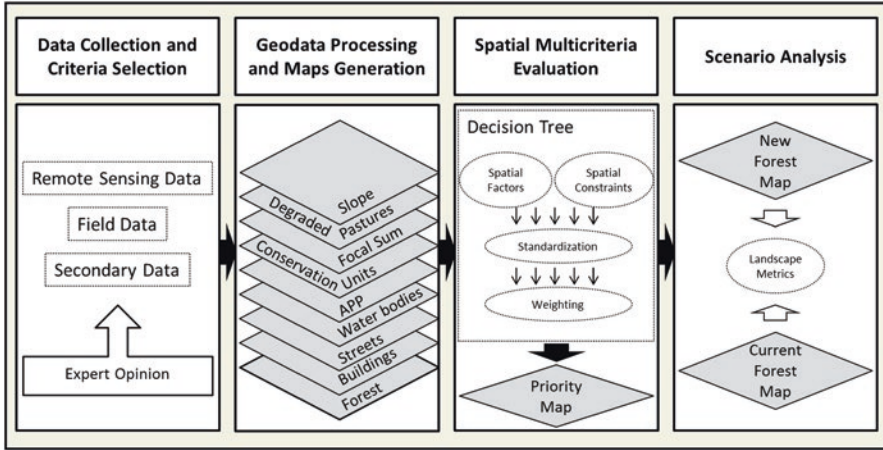


Fig. 26.2 Flow chart of applied methodology for the prioritization of sites for rehabilitation

26.2.2 Site Prioritization for Rehabilitation Measures

In this study we use spatial multicriteria evaluation (SMCE) to prioritize areas for rehabilitation as already applied in other studies (Roth et al. 2006; Orsi et al. 2011; Vettorazzi and Valente 2016). Therefore, we first selected criteria that are relevant to the selection process from an ecological and legal point of view and according related geodata (for details, see Sect. 26.2.2.1). In a next step, we processed the geodata and created raster maps. In a third step, we weighted the criteria and conducted the SMCE using the open-source software ILWIS, and last we developed different scenarios and made assumptions on the effectiveness of reforesting differently prioritized areas for forest patch quality and connectivity (Fig. 26.2).

26.2.2.1 Criteria Selection and Data Collection

For the selection of the criteria, we considered criteria selected in comparable studies (Roth et al. 2006; Orsi et al. 2011; Pedreira et al. 2011; Vettorazzi and Valente 2016), expert knowledge and experience from the field, but also the availability of data, which in our case was a limiting factor due to spatial inaccuracy or lack of appropriate spatial scale for the purpose of this study, e.g., digital soil maps at an appropriate scale or accurate cadastral data of rural properties and legal reserves. Since the aim of this study is to provide spatially explicit information on the priority of areas for reforestation according to the defined objectives, geodata with a spatial scale of 1:50,000 or lower was not considered. Based on the assumption that degraded pastures are not productive and face the increased soil loss and erosion

(Zhang et al. 2011; Dlamini et al. 2014) and due to the fact that meanwhile forest fragments in the Mata Atlântica biome are highly threatened but important for biological conservation (Joly et al. 2014), we identified the following criteria as highly important: (1) location of the areas within the landscape matrix with focus on its capacity to improve forest quality given by the focal sum of the forest cover (Roth et al. 2006), (2) degree of degradation of the pastures given by a degradation map, (3) the slope class, as degradation strongly correlates with the slope and is thus an indicator for areas prone to degradation. Additionally, five criteria were identified as spatial constraints, where reforestation is impossible: (1) current forest cover, (2) waterbodies, (3) roads, (4) buildings/settlements, and (5) areas in and outside highly protected areas (Conservation Units of Integral Protection, UCPIs, and Areas of Permanent Protection, APPs), respectively.

26.2.2.2 Geodata Processing

Land cover map In order to obtain the land cover, the RandomForest classifier (Breimann 2001) was applied using the open-source software R (R Core Team 2015) to an image product resulting from a combination of RapidEye images with the resampled SWIR bands of a SPOT 5 and a Landsat 5 TM image. For model construction, we randomly selected 60% of all pixels from each class for training and used the remaining 40% as test data. We repeated the classification task 25 times per band combination and applied a majority vote based on the 25 classification runs to further improve the final classification result. The resulting map (Fig. 26.1) has an overall accuracy of >98% with a spatial resolution of 5 m. A majority filter using the eight surrounding pixels was applied eight times repeatedly to the land cover map to smooth the classification output.

Forest cover From the land cover map described above, all pixels classified as mature or initial forest were merged into one forest class using ArcGIS. The raster was then converted into a vector data type, and the areas of the single fragments were calculated. All fragments sized smaller than 0.1 ha were subsequently removed, and the data was converted back to raster format.

Buildings and settlements Buildings and settlements were extracted from the land cover map, and the data was amplified by intense manual digitalization in Google Earth. The vector data (polygons) was converted into raster format. All areas identified as settlements or buildings were included as a spatial constraint.

Streets Streets were mapped in the field, and the data was amplified by manual digitization using aerial images from 2005/2006 from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE). For the vector data (lines), we created a buffer of 3 m and converted it to raster format. All areas identified as streets were included as spatial constraints.

Waterbodies From the land cover map, we extracted the waterbodies and waterbodies identified by INEA (Rio de Janeiro State Environmental Institute) plus waterbodies identified using Google Earth that were not included in one of the other two data sources.

Areas of Permanent Protection (Áreas de Preservação Permanente – APPs) APPs are defined by Forest Code and are composed of buffers of 30 m along the rivers of up to 10 m and slopes above 45°. This raster was created based on a shapefile provided by INEA indicating the river courses and the springs, as well as the slope map derived from the IBGE DEM with 20 m resolution. Hilltops (topos de morros) as another type of APP were not identified within the research area according to a GIS-based methodology that aims at calculating hilltops according to the National Forest Code (Castro Oliveira and Fernandes Filho 2013).

Conservation Units of Integral Protection (Unidades de Conservação de Proteção Integral – UCPI) One of the main categories of protected areas in Brazil is the conservation unit of integral protection which is restrictive to land uses. A conservation unit of integral protection map was created using the data of federal and state conservation units provided by INEA (GEPRO 2017). Três Picos State Park and Estação Ecológica Paraíso (INEA 2013) are the protected areas of this category in the study area.

Degraded pastures During a field campaign in 2011, 210 sites on pastures were mapped in the field attributing the stage of degradation as follows: no degradation visible; light degradation visible, e.g., small cattle tracks and little laminar erosion; moderate degradation visible, e.g., cattle tracks, laminar erosion, rill erosion (bras. *sulcos*), and initial and small gullies (bras. *ravinas*); and strong degradation visible, e.g., strong and broken cattle tracks, gully erosion (bras. *ravinas* and *voçorocas*). The degraded pastures were mapped by applying MESMA (multiple endmember spectral mixture analysis) using the open-source software Viper Tools 1.5 (available under <https://sites.google.com/site/ucsbviperlab/viper-tools>, last access 11/16/2017) to the image product used for the land use classification (Roberts et al. 1998, 2007; Dennison and Roberts 2003). Thereby the green vegetation fraction (GVF) was calculated on a per pixel basis. This information was then related to the degradation information of all pixels of the 210 polygons. GVF thresholds for each class were derived at the intersections of the GVF histograms calculated for each degradation classes. The thresholds were then used to classify the GVF image. In order to remove highly dynamic pastures from the classification, we masked all pixel that were identified as being dynamic using the mean absolute spectral dynamics (MASD) index (Franke et al. 2012) calculated on a time series of 5 RapidEye images from December 2010 to December 2011. The resulting degradation map with a resolution of 5 m indicates the following four stages of degradation (Fig. 26.3) – no degradation visible, light degradation visible, moderate degradation visible, and strong degradation visible – and shows an overall accuracy of near 80%.

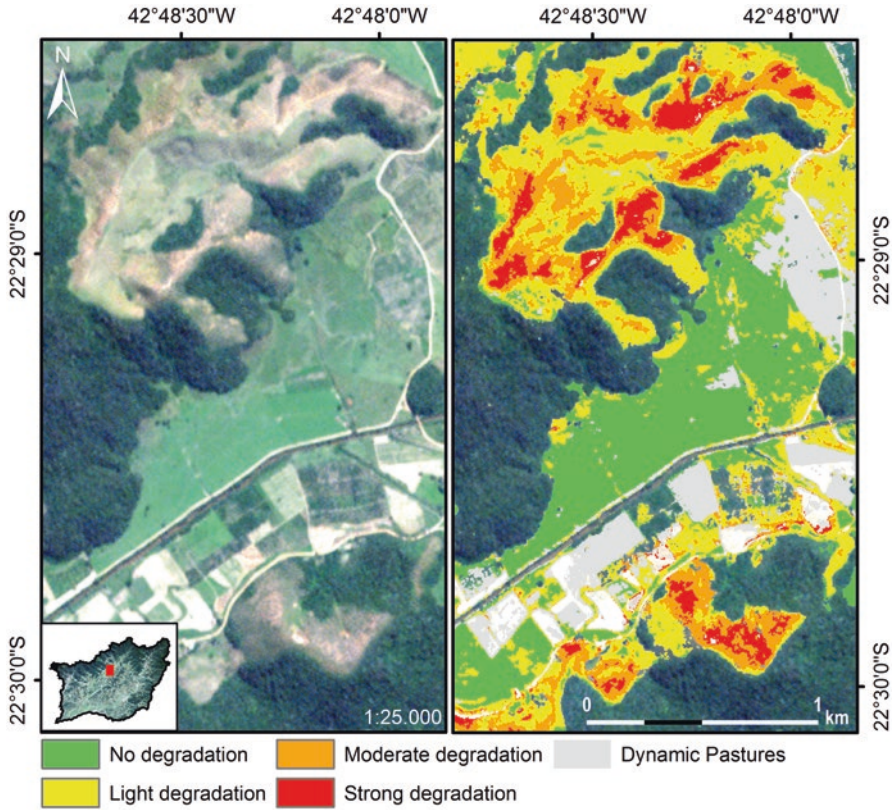


Fig. 26.3 Comparison of a subset of the degradation map (right) with the RGB-RapidEye image from 13/08/2011 (left)

Slope classes The slope was derived in degree from a DEM with 20 m spatial resolution calculated based on isolines with 10 m equidistance provided by the IBGE. As the slope angle has a major impact on pasture degradation processes and soil loss (Liu et al. 1994), we related the degraded pastures to eight slope classes. On slopes with more than 10°, the share of degraded pastures accounted for more than 75%, more than 28% of which are moderately to strongly degraded. Slope classes were thus defined based on these findings and legal aspects stated in the Brazilian Forest Code (Brazilian Federal Law 12651, May 25, 2012) as follows: 0–10°, 10–25°, 25–45°, and > 45°. These classes are also in accordance with the findings by Lepsch et al. 1991 who state that slopes above 9° inclination are easily eroded (except those being highly permeable including sandy soils).

Potential forest corridor (focal sum raster of the forest cover) Based on the forest cover raster, we applied the focal sum functionality of ArcGIS (Fig. 26.4), as suggested by Singleton and McRae (2013). A kernel of 99 was applied to the forest raster which equals 495 m. Thereby, a raster indicating how many forest pixels are located within the kernel of each pixel was created.

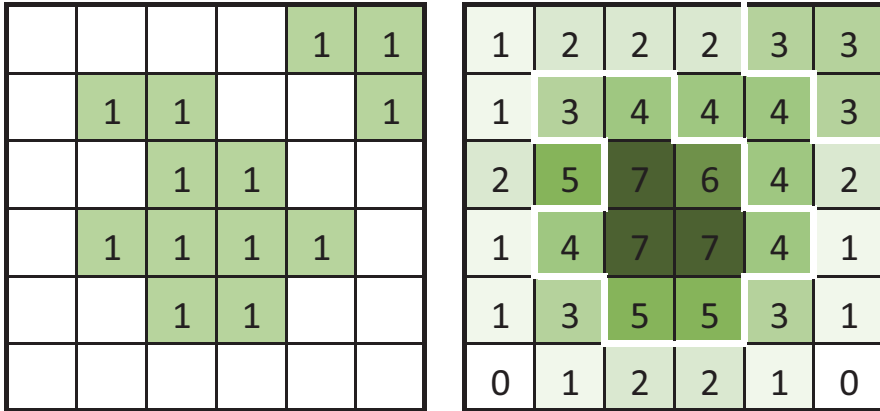


Fig. 26.4 Schematic graphic of the focal sum functionality. Areas filling gaps of the patches or those ones in their vicinity receive higher values and will thus be prioritized

26.2.2.3 Standardization, Weighting, and Spatial Multicriteria Evaluation

In our study we use spatial multicriteria evaluation (SMCE) to identify areas that should be prioritized for reforestation under ecological and legal principles. For the analysis, we use the open-access software ILWIS (52°North ILWIS Community 2015). All criteria were standardized to 0–1 in order to make them comparable (Table 26.1).

Criteria weighting was done by pairwise comparison according to Saaty (1980) using a nine-step scale (Table 26.2). The focal sum parameter and the degradation status of the pastures were set to be equally important, whereas both were set to be moderately more important than the slope classes. Thereby we obtained the following weights: focal sum = 0.43, status of pastures = 0.43, and slope classes = 0.14. Based on these weights, we derived the priority maps once for the area inside and once outside the protected areas.

26.2.3 Scenario Development

In order to test the impact of the identified priority areas on the existing forest cover, we created different scenarios based on the identified priorities. Therefore, we merged the results of the priority maps for in and outside the protected areas (UCPIs and APPs). We then extracted the areas with priority values of 0.8–1.0 (Scenario A) and merged these areas with the actual forest cover. We repeated this step for the areas 0.7–1.0 (Scenario B), 0.6–1.0 (Scenario C), and 0.5–1.0 (Scenario D). Based on these hypothetical forest rasters, we calculated different patch parameters for the

Table 26.1 Overview of the criteria and the standardization used (Spatial constraints: 1 = yes, 0 = no. Spatial factors: 1 = very important, 0 = not important)

| Criterion | Criteria type | Standardization |
|-------------------|--------------------|--|
| Forest | Spatial constraint | Forest = 1/no forest = 0 |
| Buildings | Spatial constraint | Buildings = 1/no buildings = 0 |
| Streets | Spatial constraint | Streets = 1/no streets = 0 |
| Waterbodies | Spatial constraint | Waterbodies = 1/no waterbodies = 0 |
| UCPI_APPS | Spatial constraint | UCPI_APPS = 1/no UCPI_APPS = 0 (used to map the area outside the protected areas) |
| | | UCPI_APPS = 0/no UCPI_APPS = 1 (used to map the area inside the protected areas) |
| Focal sum | Spatial factor | 4900.5–9801 = 1/0–4900.5 = 0–1 (linear) |
| Degraded pastures | Spatial factor | 1: No degradation = 0 2: Light degradation = 0.5 3: Moderate degradation = 0.75 4: Strong degradation = 1 |
| Slope classes | Spatial factor | 1: 0–10° = 0 2: 10–25° = 0.5 3: 25–45° = 0.75 4: >45° = 1 |

Table 26.2 Nine-step matrix developed by Saaty (1980) to identify the criteria weights by applying pairwise comparison

| Index | Definition | Calculation |
|-------|------------------------------|-------------|
| –4 | Extremely less important | 1/5 |
| –3 | Very strongly less important | 1/4 |
| –2 | Strongly less important | 1/3 |
| –1 | Moderately less important | 1/2 |
| 0 | Equally important | 1/1 |
| 1 | Moderately more important | 2 |
| 2 | Strongly more important | 3 |
| 3 | Very strongly less important | 4 |
| 4 | Extremely more important | 5 |

scenario-based forest fragments using the open-source software FRAGSTATS 4.2 (McGarigal et al. 2012). We compared the mean values for each parameter of each scenario to those calculated for the actual forest fragments in 2011. For the edge-dependent parameter, we assumed an edge effect of 100 m according to Ribeiro et al. 2009 and findings by Thier and Wesenberg (2016). The following eight parameters for patch size, shape, and connectivity/degree of isolation were of special interest (for detailed information, please refer to the FRAGSTATS documentation (McGarigal et al. 2012)):

- I. Class area (CA): a measure of total forest cover.
- II. Mean parameter-area-ratio (PARA): a shape metric which relates the patch perimeter to its area.

- III. Mean shape index (SHAPE): another shape metric that relates the patch perimeter to its area with an adjustment for a standardized measure.
- IV. Mean contiguity index (CONTIG): a metric of patch shape which measures the spatial connectedness of cells within a patch.
- V. Total core area (TCA): a measure of the sum of the core areas of each forest patch.
- VI. Mean core area index (CAI): where CAI is the percentage of each patch, that is core area, and mean CAI is the average of all CAI of the landscape.
- VII. Mean proximity index (PROX): an aggregation metric that measures for each patch, the sum of patch area divided by the distance squared between the focus patch and other patch, within a specified distance.
- VIII. Mean Euclidean nearest neighbor (ENN): another aggregation metric. ENN measures the distance between two patches.

26.3 Results

26.3.1 *Prioritization of Areas for Rehabilitation*

In our analysis we focused on the prioritization of areas in and outside protected areas based on three main criteria: (i) the as-is state of the pastures, (ii) the importance of the area for connectivity or improving patch shape, and (iii) the inclination of the slope. Of the whole study area (approx. 460 km²), i.e., around 250 km² were taken into account for the SMCE. Of these 250 km², 20% (approx. 50 km²) are protected by law as UCPI and APPs and must be preserved. That is the reason why we decided to analyze them separately.

26.3.2 *Characteristics of the Prioritized Areas*

Compared to the areas within the protected areas, there are relatively more areas of moderate to high priorities outside the protected area according to our criteria (Fig. 26.5).

Figures 26.6 and 26.7 show maps of the identified priority areas outside (Fig. 26.6) and inside protected areas, i.e., areas within UCPIs and APPs: buffers of river and spring plus areas above 45° slope (Fig. 26.7). In both cases we identified several high-priority areas in close vicinity to forest patches. Meanwhile high-priority sites outside protected areas can be found more or less equally distributed within the watershed, especially in close vicinity to the larger fragment in the central part of the watershed as well as at the edges of the PETP. Most of the high-priority areas inside the protected areas are located within the UCPI. On the assumption that most of the high-priority sites within the protected areas seem to be mainly located within the UCPI is from our understanding due to the fact that most

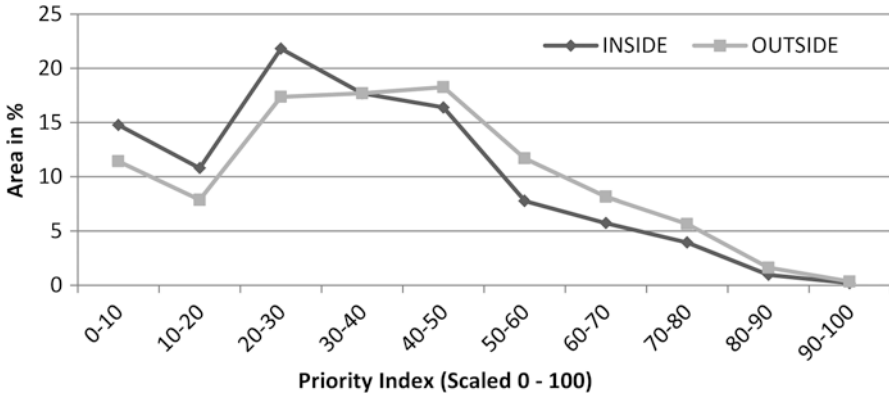


Fig. 26.5 The graph illustrates the distribution of priority values in % for the areas in and outside the protected areas (UCPI/APPs)

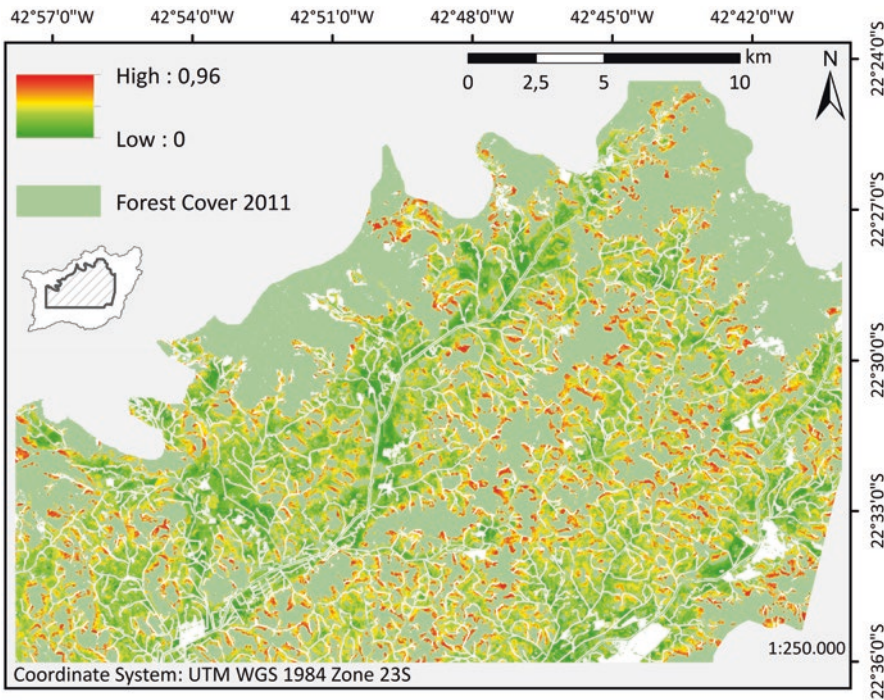


Fig. 26.6 Priority maps for the areas outside the protected areas (UCPI/APP). Low priorities are given in green and highest priority in red

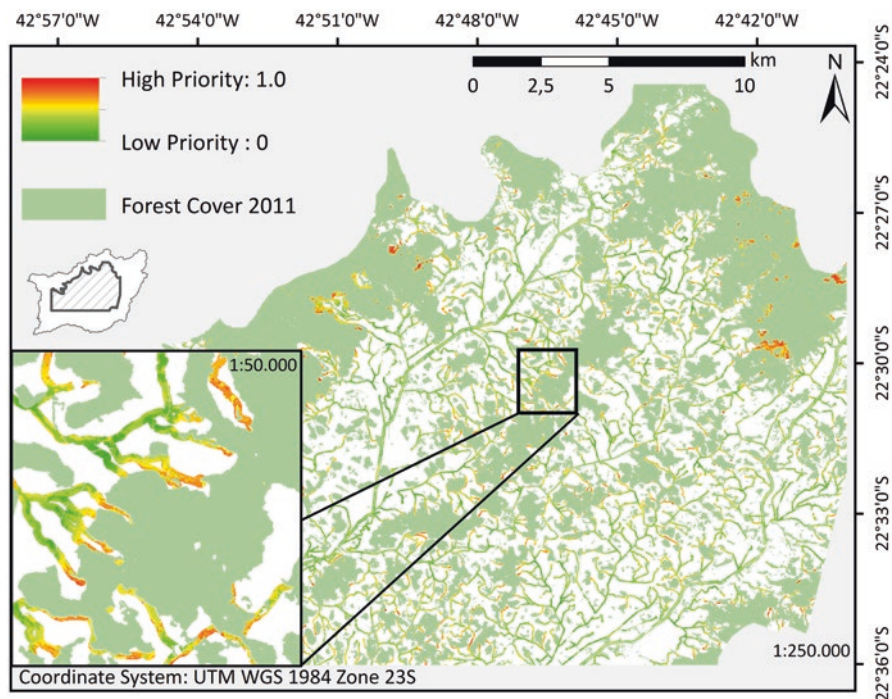


Fig. 26.7 Priority maps for the areas inside the protected areas (UCPI/APP). Low priorities are given in green and highest priority in red

Table 26.3 The table shows the class majorities of the degradation classes and the slope classes per priority class for areas in and outside protected areas

| | Priority classes | | | | | | | | | |
|-------------------------------|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| | 0.0–0.1 | 0.1–0.2 | 0.2–0.3 | 0.3–0.4 | 0.4–0.5 | 0.5–0.6 | 0.6–0.7 | 0.7–0.8 | 0.8–0.9 | 0.9–1.0 |
| Pasture degradation (outside) | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 4 |
| Pasture degradation (inside) | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 4 |
| Slope class (outside) | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 4 |
| Slope class (inside) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |

of the APP area is located along rivers and that within the APP area there seem to be less moderately to strongly degraded pastures than outside the protected areas.

We calculated the class majority of the degraded pastures and the slope classes per priority class for both areas to get a further insight of the identified priorities. Table 26.3 indicates the different majority values for in and outside protected areas per priority class. The areas of the highest priorities (0.8–1.0) are mainly located on

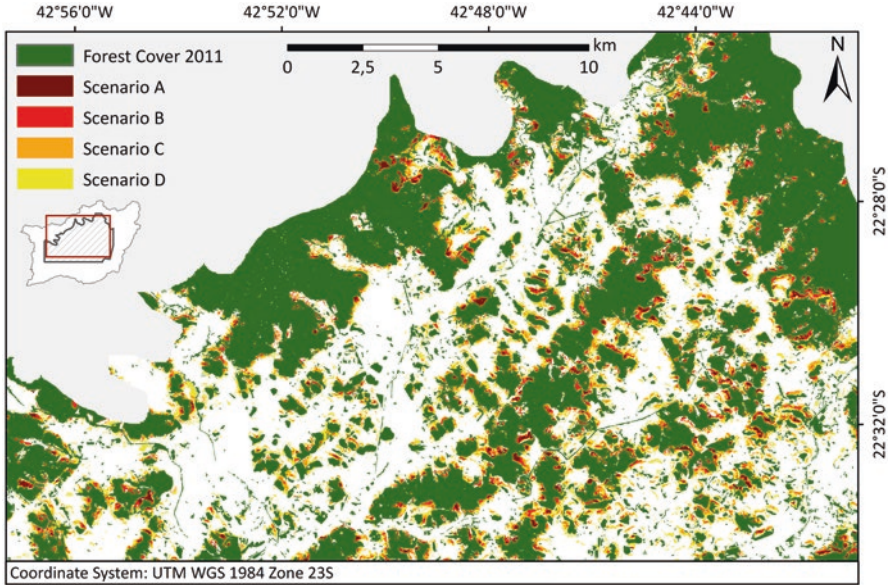


Fig. 26.8 Overview of the different scenarios developed for the study area

moderately to strongly degraded pastures on slopes $>25^\circ$ for areas outside protected areas and on slopes $10\text{--}25^\circ$ for areas inside protected areas. This fact may support the conclusion that most of the high-priority areas inside protected areas are located within UCPIs, as the UCPI area is located at the foothills of the Serra dos Órgãos with steeper slopes than the APP area.

26.3.3 Hypothetical Improvement of Forest Quality

For a more detailed comprehension on the impact of possible reforestation in prioritized areas according to our priority maps, we compared patch parameter of the original forest cover 2011 with what-if scenarios of the forest cover when being enlarged by afforesting certain prioritized areas (Fig. 26.8).

The results in Table 26.4 indicate clearly that afforesting the prioritized areas with a priority index of 0.8–1.0, with only 4.3 km² would have the relatively largest impact on area, patch shape, and proximity parameters compared to the other scenarios. This would benefit the forest patches enormously, even though no absolute gain in total core area (assuming an edge of 100 m) will be achieved. A gain in total core area is only recognizable from scenario (B) to (D).

Table 26.4 Comparison of the forest parameter calculated for the original forest cover 2011 and the four created scenarios, where TA, total area in km²; AA, additional area in km²; PARA, parameter-area-ratio; SHAPE, shape index; CONTIG, contingency index; TCA, total core area; PROX, proximity index; and ENN, Euclidean nearest neighbor

| Scenario | TA | AA | PARA (mean) | SHAPE (mean) | CONTIG (mean) | TCA | PROX (mean) | ENN (mean) |
|----------------------------|-------|------|----------------|-----------------|------------------|--------|----------------|---------------|
| Forest 2011 | 188.6 | 0.0 | 1097.0 | 1.8 | 0.8 | 5942.2 | 4836.1 | 55.4 |
| (A) Forest 11 (0.8–1.0) | 192.9 | 4.3 | 3170.0 | 1.5 | 0.6 | 5942.4 | 23577.4 | 34.3 |
| (B) Forest 11 (0.7–1.0) | 205.7 | 17.1 | 4002.9 | 1.4 | 0.5 | 5966.0 | 34235.3 | 27.9 |
| (C) Forest 11 (0.6–1.0) | 224.4 | 35.8 | 4530.1 | 1.4 | 0.4 | 5978.2 | 40792.1 | 23.4 |
| (D) Forest 11 (0.5–1.0) | 250.9 | 62.3 | 4928.3 | 1.3 | 0.4 | 6045.5 | 61634.4 | 20.6 |

26.4 Discussion

The presented methodology was especially developed for pasture-dominated environments with strong forest fragmentation. From our understanding, highly degraded areas, being located on steep slopes prone to further degradation and in close vicinity to forest fragments, where they would improve the patch shape and/or the connectivity between fragments when being reforested, should be considered priority for rehabilitation. We believe that our approach properly identified those areas that match the mentioned criteria.

In this study we used only high-resolution data on the degradation status of the pastures, the focal sum raster of the forest cover, and the slope classes with appropriate resolutions to select small priority sites. For the focal sum raster of the forest cover, we used a Kernel of 99 (495 m). This kernel has been proper for our study area, as it identified successfully important sites for improving forest shape and connectivity. Further studies might however be required to systematize best kernel sizes for different landscapes. The slope map used in our study was derived from a 20 m DEM. Improved resolution of the source DEM could also improve the identification of steep slopes. In general, it was difficult to obtain high-resolution data for the study area, one reason why most of the data was produced by the author to fit the requirements. Missing data, such as high-resolution soil map or data on the soil susceptibility to erosion, could have been very interesting supportive data. Soil map was only available with a scale of 1:250,000, but we recommend not mixing the scales. We also would have liked to consider information on the landownership, as landowners must conserve 20% of their land as forests. Unfortunately, this data is not available. Recently obtained spatial information from the Rural Environmental Survey (Cadastro Ambiental Rural – CAR) is also not ready to use at the moment due to high spatial inaccuracies and missing data. From an ecological perspective, however, it is important to identify areas of high ecological value in the first place.

The integration of socioeconomic information may be added subsequently. However, this does not mean that socioeconomic criteria are not necessary. Its integration with the criteria presented in this work is highly encouraged.

Prioritizing areas always depends on the selected criteria, the data quality, availability and scale, and the preferences of the decision-maker who gives the weights to the criteria. Thus, the final priority maps may always differ and should mainly be regarded as a supportive information to environmental and landscape planners. According to Malczewski (1996), the final decision should be taken based on different alternatives prepared by several groups or individuals of different interests. Also thresholding and classifying the priority values are again a quite subjective task. We decided to use equal classes of steps of 0.1. However, there are many possibilities to classify the final results depending on the purpose, e.g., using jerks to create equally area size classes.

We are convinced that the presented approach could further be used to adapt schemes for payments for ecosystem services by giving different incentives to areas of different priorities in order to increase the willingness of the landowners to rehabilitate areas of high ecological importance, although some more research might be needed to properly transfer our methodology into a legal framework.

26.5 Conclusion

The above-described method identifies high-priority areas within and outside conservation units (UCPIs and APPs) for increasing forest cover and enhancing forest shape and connectivity. Using patch parameter to make further statements on the quality of the prioritized areas showed to be very effective. The information obtained from the scenario comparison proves the effectiveness of our methodology, the selected criteria, and the weights given for the specific aim of our study.

Related to the issue of data availability and quality we mentioned in the methods and the discussion, we would like to emphasize the importance of proper geoprocessing and the development of properly georeferenced geodata, as they are indispensable for any kind of spatial analysis. Thus, the development of a high-resolution geodatabase based on surveying technology should be of highest priority to support environmental management and public policies.

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References

- 52°North ILWIS Community (2015) Integrated Land and Water Information System – ILWIS. Version 3.8.5, Released September 3rd, 2015. Under GPL
- Breimann L (2001) Random forests. *Machine Learn* 45(1). Kluwer Academic Publishers):5–32. <https://doi.org/10.1023/A:1010933404324>
- Cabral DC (2004) Produtores rurais e indústria madeireira no Rio de Janeiro do final do século XVIII – Evidências Empíricas Para a Região do Vale do Macacu. *Ambiente & Sociedade* 7(2):125–145
- Carneiro MJT, Latini JL, Coelho TD et al (2012) Histórico do processo de ocupação das bacias hidrográficas dos rios Guapi-Macacu e Caceribu. *Embrapa Solos. Série Documentos/ Embrapa Solos, Rio de Janeiro*, p 152
- Dean W (1997) A ferro e fogo: a história da devastação da Mata Atlântica brasileira. Companhia das Letras, Rio de Janeiro
- Dennison PE, Roberts DA (2003) Endmember selection for multiple endmember spectral mixture analysis using endmember average RMSE. *Remote Sens Environ* 87(2–3):123–135. [https://doi.org/10.1016/S0034-4257\(03\)00135-4](https://doi.org/10.1016/S0034-4257(03)00135-4)
- Dlamini P, Chivenge P, Manson A, Chaplot V (2014) Land degradation impact on soil organic carbon and nitrogen stocks of sub-tropical humid grasslands in South Africa. *Geoderma* 235-236:372–381. <https://doi.org/10.1016/j.geoderma.2014.07.016>
- Fidalgo ECC, Thompson D, Naegeli de Torres F, Mendonça RN (2014) Comparative analysis between estimated soil loss and occurrence of erosion: a case study in Guapi-Macacu watershed, RJ. In: Moura MF, Pellegrino GQ, Rodrigues LN (eds) *Impactos da agricultura e das mudanças climáticas nos recursos hídricos: anais*. Campinas, SP, 25 a 27 de março 2014. Embrapa, Brasília, DF
- Franke J, Keuck V, Siegert F (2012) Assessment of grassland use intensity by remote sensing to support conservation schemes. *J Nat Conserv* 20(3):125–134. <https://doi.org/10.1016/j.jnc.2012.02.001>
- GEPRO (2017) Unidades de Conservação da natureza no estado do Rio de Janeiro. Map and digital data.. <http://geproinearj.blogspot.com.br/p/nucleos.html>. Accessed 23 Oct 2017
- Gjorup AF, Fidalgo ECC, Prado RB, Schuler AE (2016) Análise de procedimentos para seleção de áreas prioritárias em programas de pagamento por serviços ambientais hídricos. *Rev Ambient Água* 11(1):225–238
- Gurr GM, Johnson AC, Liu J (2014) Land use: restoration and rehabilitation. Reference Module in Food Science – *Encyclopedia of Agriculture and Food Systems* 139–142
- INEA (2013) Parque estadual dos três picos: Plano de manejo. Resumo executivo. Instituto Estadual do Ambiente, Rio de Janeiro. [http://r1.ufrrj.br/lmbh/pdf/ensino/MAS/2017-I/MAS%20Dinamica%2003%20\(texto\)%20\(2017%201\).pdf](http://r1.ufrrj.br/lmbh/pdf/ensino/MAS/2017-I/MAS%20Dinamica%2003%20(texto)%20(2017%201).pdf). Accessed 20 Apr 2017
- Joly CA, Metzger JP, Tabarelli M (2014) Experiences from the Brazilian Atlantic Forest: ecological findings and conservation initiatives. *New Phytol* 204:459–473
- Lepsch IF, Bellinazzi JRR, Bertolini D, Espíndola CR (1991) Manual para levantamento utilitário do meio físico e classificação de terras no sistema de capacidade de uso, 4th edn. Sociedade Brasileira de Ciência do Solo, Campinas, SP
- Liu BY, Nearing MA, Risse LM (1994) Slope gradient effects on soil loss for steep slopes. *Trans ASAE* 37(6):1835–1840
- Malczewski J (1996) A GIS-based approach to multiple criteria group decision-making. *Int J Geogr Inf Syst* 10:955–971
- Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. *Int J Geogr Inf Sci* 20(7):703–726
- McGarigal K, Cushman SA, Ene E (2012) FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. Computer software program produced by the authors at the University of Massachusetts, Amherst.. <http://www.umass.edu/landeco/research/fragstats/fragstats.html>. Accessed 23 Oct 2017

- Nehren U (2008) Quartäre Landschaftsgenese und historische -dedradation in der Serra dos Órgaos, Rio de Janeiro. Dissertation, Universität Leipzig, Leipzig
- Nehren U, Kirchner A, Sattler D et al (2013) Impact of natural climate change and historical land use on landscape development in the Atlantic Forest of Rio de Janeiro, Brazil. *An Acad Bras Cienc* 85(2). <https://doi.org/10.1590/S0001-37652013000200004>
- Oliveira GC, Fernandes Filho EI (2013) Metodologia para delimitação de APPs em topos de morros segundo o novo Código Florestal brasileiro utilizando sistemas de informação geográfica. *Anais XVI Simpósio Brasileiro de Sensoriamento Remoto – SBSR, Foz do Iguaçu, PR, Brasil, 13.-18. of april 2013, INPE*
- Orsi F, Geneletti D, Newton AC (2011) Towards a common set of criteria and indicators to identify forest restoration priorities: an expert panel-based approach. *Ecol Indic* 11:337–347
- Pedreira BCC, Fidalgo ECC, Abreu MB (2009) Mapeamento do uso e cobertura da terra da bacia hidrográfica do Rio Guapi-Macacu, RJ. *Anais XIV Simposio Brasileiro de Sensoriamento Remoto - SBSR, Natal, RN, Brasil, 25.-30. of april 2009, INPE*
- R Core Team (2015) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna
- Ribeiro MC, Metzger JP, Martensen AC et al (2009) The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. *Biol Conserv*:1141–1153. <https://doi.org/10.1016/j.biocon.2009.02.021>
- Roberts DA, Gardner M, Church R et al (1998) Mapping chaparral in the Santa Monica Mountains using multiple endmember spectral mixture models. *Remote Sens Environ*:267–279. [https://doi.org/10.1016/S0034-4257\(98\)00037-6](https://doi.org/10.1016/S0034-4257(98)00037-6)
- Roberts DA, Halligan KQ, Dennison, PE (2007) VIPER tools user manual (version 1.5). University of California at Santa Barbara.. <https://sites.google.com/site/ucsbvipperlabor/viper-tools>. Accessed 16 Nov 2017
- Rodrigues RR, Brancalion PHS, Isemhagen I (eds) (2009) Pacto pela restauração da Mata Atlântica: referencial dos conceitos e ações de restauração florestal. LERF/ESALQ: Instituto BioAtlântica, São Paulo
- Roth RE, Zhu A-X, Holbus E et al (2006) An automated approach to site selection for ecological restoration in fragmented landscapes. *Geogr Inform Sci* 12(2):98–105
- Saaty TL (1980) The analytic hierarchy process: planning setting priorities, resource allocation. McGraw-Hill International, New York
- Singleton PH, McRae BH (2013) Chapter 10: Assessing habitat connectivity. In: Craighead FL, Convis CL (eds) *Conservation planning: shaping the future*. ESRI Press, Redlands
- Thier O, Wesenberg J (2016) Floristic composition and edge-induced homogenization in tree communities in the fragmented Atlantic rainforest of Rio de Janeiro, Brazil. *Trop Conserv Sci* 9(2):852–876
- Vettorazzi CA, Valente RA (2016) Priority areas for forest restoration aiming at the conservation of water resources. *Ecol Eng* 94:255–267. <https://doi.org/10.1016/j.ecoleng.2016.05.069>
- Zhang G, Kang Y, Han G et al (2011) Grassland degradation reduces the carbon sequestration capacity of the vegetation and enhances the soil carbon and nitrogen loss. *Acta Agric Scand Sect B Soil Plant Sci* 61(4):356–364. <https://doi.org/10.1080/09064710.2010.495079>