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Ecological Restoration Indicators apllied to Permanent Preservation Areas surrounding the springs

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ABSTRACT

The ecological indicators have been used to study riparian ecosystems affected by the expansion of agrosilvopastoral activities. The concern with the current environmental degradation scenario demands efficient evaluation methods and tools for environmental management. In this context, this paper aims to present a cheaper way to analyze the ecological restoration process trajectory of Permanent Preservation Areas (PPA) surrounding the springs in different degradation degrees, using a Rapid Assessment Protocol (RAP). The RAP is based on a union between remote optical remote sensing data (MODIS EVI2 time series) and in–situ environmental assessment, which it was used to analyze the trajectory of the process of environmental restoration of PPA surrounding the springs in different restoration stages, in the Southern of Minas Gerais, Brazil. The part I, in Environmental Assessment in-situ, there was a decrease in a number of degraded PPA after nine years, which show the environmental improvement of these areas. Although the family agriculture is predominant in Southern of Minas Gerais, the presence of the remaining native vegetation still being essential for triggering or accelerating the ecological restoration process of degraded areas, which its enable natural regeneration conduction and the ecological processes reestablishment. The part II, the time series analysis got partial information about the trajectory of the ecological restoration process of PPA - they could be influenced by the non-forest physiognomies -, however, we observed difference between PPA and reference areas using the cumulative EVI2 and clustering analysis, which separated them into classes. Furthermore, the reports provided the changes evaluate, which occurred over time, either the natural succession of PPA surrounding springs or the advance of agricultural crops and/or pasture forward inland of PPA. These ecological indicators are cheaper and useful to determinate the current condition of a specific ecosystem and to enable detecting change over time. Therefore, this RAP may establish a cheaper basis for the ecological restoration programs, and assesses limiting factors toward the monitoring process of PPA in different degrees of degradation.

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Australian Journal of Basic and Applied Sciences, 10(9) May 2016, Pages: 132-139

INTRODUCTION

The Southeast of Brazil is a well-developed economic region where concentrates the biggest part of the Brazilian population and it is located the Atlantic Forest, which is considered a world hotspot and a threatened biome (Ribeiro *et al*., 2009). Among the most threatened ecosystems, there are riparian forests which play an important role in maintaining the water bodies ecological equilibrium including the corridor function (Martins, 2014). However, the conversion of natural vegetation to agricultural land over the centuries has caused the fragmentation and reduction of these landscapes in this biome (Ribeiro *et al*., 2009). These environmental impacts are real even the Brazilian Forest Code (12.651/2012) had established the protection of riparian vegetation surrounding watercourses, springs and natural reservoirs, called Permanent Preservation Areas (PPA).

The concern with the current environmental degradation scenario demands efficient evaluation methods and tools for environmental management (Melo *et al*., 2013). In this context, the forest ecosystems are usually monitored by means of quantitative methods with high sampling effort to determine vegetation composition and species richness such as forest inventory (Rodrigues *et al*., 2009). However, there are rapid assessment protocols (RAP) (Callisto *et al*., 2002) have been developed to evaluate the structure and functioning of riparian ecosystems and contribute to the management and preservation of these environments using parameters that are easy to understand and apply (Faria *et al*., 2012).

For instance, there are cheaper tools which may help in environmental monitoring such as the time series analysis from remote sensing data (Bernardes *et al*., 2012). The time series MODIS is recognized as an effective tool in landscape detection change over time (Freitas *et al*., 2011).

In riparian zones, there are specific environmental conditions may be considered in ecological restoration projects (Martins, 2014), mainly in Permanent Preservation Areas (PPA) surrounding the springs – riparian areas must be protected in a radius of 50 meters from spring water-eyed, as outlined in the Brazilian Forest Code (12.651/2012). Thus, a qualified professional can design a protocol describing the analysis of biotic and abiotic variables of PPAs and determining qualitative and quantitative ecological indicators (Bjorkland *et al*., 2001).

In this context, this paper aims to present a cheaper way to analyze the ecological restoration process trajectory of PPA surrounding the springs in different degradation degrees, using a rapid assessment protocol (RAP). The RAP was focused in (i) to evaluate the restoration process on the conservation of PPA, in relation to land use, stage of conservation of riparian vegetation and soil around nine years after the beginning of the ecological restoration process; and (ii) analysing environmental trajectory in land use/land cover (LULC) during nine years, by means of MODIS EVI2 time series of PPA.

MATERIALS AND METHODS

Site characterization:

The study was realized in twenty-nine PPAs located in southern of Minas Gerais, Brazil: Ingaí, Itumirim, Itutinga, Lavras, Nazareno and São João del-Rei. The climate according to Köppen classification is a transition between Cwa and Cwb, characterized by humid temperate climate with dry winter and moderate summer (Sá Júnior *et al*., 2012). The PPA phytophisiognomy is Semideciduous Forest.

The RAP involved the integration of the following tools:

1. Environmental assessment *in situ*
2. Time series analysis by remote sensing data.

PPA Environmental Assessment:

In 2004 and 2005, the PPA surrounding twenty-nine springs (radius of 50 meters) were isolated using wire fence, according to current Brazilian Federal Legislation. The model of forest restoration used was the artificial regeneration by planting native seedlings using 5×5 meters and 8×8 meters spacing, according to the stage of conservation.

The PPA degradation degree was the main selection criterion for the environmental assessment and the applied restoration methodology. The PPAs were selected on the results described in Faria *et al*. (2012) and classified according to Pinto *et al*. (2004) in: preserved, disturbed or degraded areas.

The environmental assessment of PPAs were based in Faria *et al*. (2012) and Bjorkland *et al*. (2001) model. This protocol criteria was composed by the area general characterization and the environmental aspects about the conservation stage of the riparian vegetation, soil and its forms of use (Figure 1).

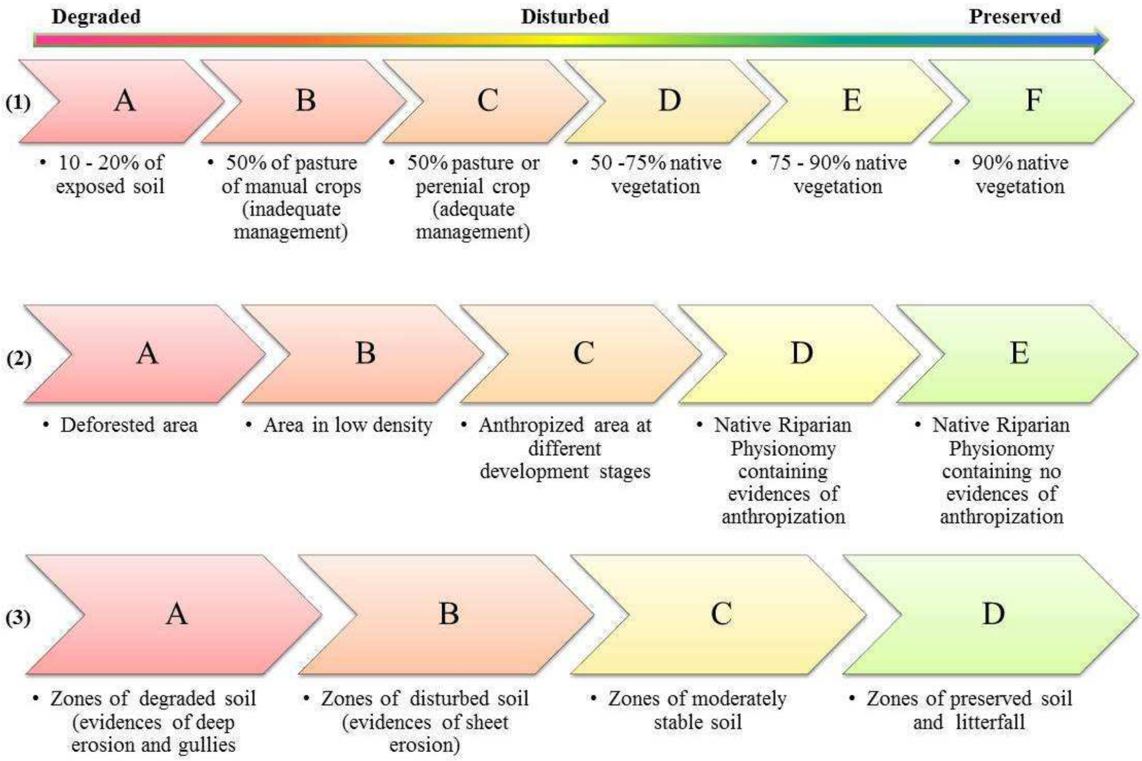

Fig. 1: Flowchart of criteria used for the (1) land use, (2) stage of conservation of the riparian vegetation, and (3) stage of soil conservation.

In this context, Faria *et al*. (2012) attached different scores and weights according to the importance of each aspect. The fiels trips were made in 2014.

Time series analysis:

The temporal analysis tool was developed by Freitas *et al*. (2011), using MODIS data (MOD13Q1). This tool detect changes in South America surface (Freitas *et al*., 2011).

The vegetation index used was the EVI2 (Enhanced Vegetation Index 2). The EVI2 function was based on the photosynthetic pigments availability (Jiang *et al*., 2008), using the *Red* and *NIR* (near- infrared) bands (Freitas *et al*., 2011):

$$EVI2 = \frac{2{,}5 \cdot NIR - Red}{(NIR + 2.4 \cdot Red + 1)} \tag{1}$$

For reference, the MODIS pixels, represented by polygons, we visually interpreted high-resolution QuickBird imagery in Google Earth (figure 2). There are two types of MODIS EVI2 time series: the red line filtered *with wavelet* and the blue line filtered *without wavelet* (Freitas *et al*., 2011).

In addition to EVI2 time series, there is the local rainfall index (product 3B43-V6), available by TRMM (Tropical Rainfall Measuring Mission) (Freitas *et al*., 2011).

We did a preliminary analysis of each PPA to select those on which their area (radius of 50 meters) would fit the MODIS pixel. Then, we were selected four PPAs with different degradation degrees:one preserved and three disturbed areas (figure 2).

Australian Journal of Basic and Applied Sciences, 10(9) May 2016, Pages: 132-139

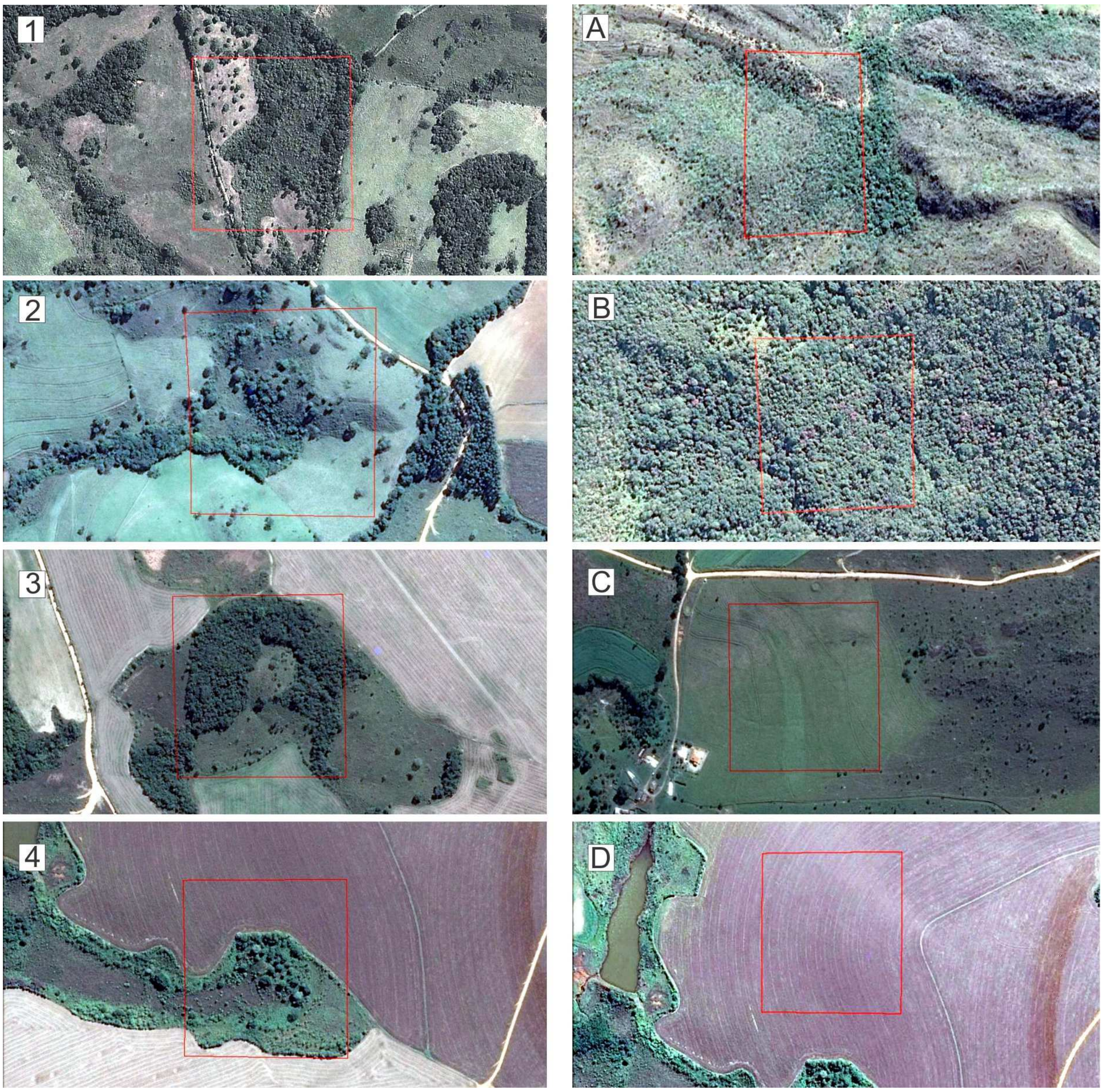

Fig. 2: Interface between Google Earth images and MODIS pixels limits which they were selected for temporal analysis. The areas represented by numbers from 1 to 4 showed PPA and from A to D figured by the reference areas: Cerrado Sensu Stricto, Semideciduous Forest, Pasture and Plantation, respectly.

There is spatial heterogeneity in each PPA pixel which may influence the temporal signature of each one, since the presence of different objects will result in a single value for each pixel sampled (Bernardes *et al*., 2012). Thus, we compared the PPAs time series with four homogeneous areas located in southern of Minas Gerais. These areas occupied 100% of MODIS pixel (pure pixel) called “reference area”. We selected these areas according to vegetal physiognomy, forms of soil use, and location (Figure 3): Cerrado *Sensu Stricto*, Semideciduous Forest (Oliveira- Filho & Fluminhan-Filho, 1999), Pasture and Plantation.

Statistical analysis:

We used basic statistical parameters and cumulative EVI2 values from 2003 (the previous year of the implementation of ecological restoration methods) to 2012 (EVI2 time series available). We also used the clustering analysis (Anjos *et al*., 2013). The estimates were obtained for each PPA and for the reference area.

The possible correlation between EVI2 and rainfall indexes (TRMM) were analysed by Pearson's correlation coefficient from 2003 to 2012, at 5% of significance.

The STATISTICA v7.0 package was used for the statistical analysis.

Results

PPA Environmental Assessment:

We observed an increasing in about 38% of PPA which showed a success in the process of ecological restoration from degraded to perturbed (9), or to preserved (2).

In relation to forms of land use, there is about 37.93% of PPA with more than 50% of native vegetation. On the other hand, there are 41.38% of PPA (12) with more than 50% occupied for plantation or pasture, filling the categories B and C. The PPA were grouped on these categories, even isolated, they exhibited traces of animals grazing and other anthropic interventions. The remaining PPA was represented in categories A, E and F (6.90% each one). We observed the inadequate management of soil and its land use could affect directly the forests dynamic of the riparian ecosystem (Rodrigues *et al*., 2009; Aguiar *et al*., 2011). In Southern of Minas Gerais, there are small rural properties where the deforestation and the conversion of these PPA in pastures land and agricultural crops is common for family farming.

In relation to conservation stage of the riparian forest, we observed about 82.76% PPA with distinct physiognomies in different stages of development, with or without anthropization (categories C and D). The A and B categories indicated the advanced stage of degradation forest and no evidence of natural regeneration. Thus, the forest landscapes surrounding springs play as potential nucleus of seed propagation and local recolonization (Martins, 2014).

The artificial regeneration was used as PPA restoration method have been work as source of propagules dissemination. However, the survival rate of seedlings was lower than 30% on the majority of PPAs. On the other hand, we found the presence of regenerative potential stratum with surviving seedlings. One of limiting factors of natural regeneration of these PPAs was the exotic grasses, the most common is *Brachiaria* sp., it would be controlled (Martins, 2014).

In reference to the conservation of soil, there is 72.41% of PPAs (category C) with soils covered by native vegetation or exotic grass or annual crop, and somehow the surface water runoff was absorbed or retained. On the other hand, Faria *et al*. (2012) observed 45% of PPAs with compacted soil (cattle stepping), evidences of sheet erosion, and weak regeneration in environmental assessment made in 2005 (Faria *et al*., 2012). On this aspect, we observed the forest isolation, the *Brachiaria* sp. growth management and seedlings planting were important to avoid erosive processes and the other drivers of soil degradation (Pinto *et al*.,2004).

Time series Analysis:

The comparison analysis between PPA and reference area temporal signatures were performed to assess the environmental trajectory from 2003 to 2012 (Figure 3).

The PPA 1 (Figure 3.1), diagnosed as preserved, showed similar temporal signature to the Semideciduous Forest (Figure 3B), when we observed the high EVI2 values in rainfall periods. The PPA 1 temporal signature showed partially the ecological restoration process, which comprised the arboreal individuals in development up to 8 meters height surrounding the water-eyed.

The PPA 2 and PPA 3 (Figure 3.2 and 3.3) were characterized as areas on different stages of development, which there were non-continuous forestry strata (Rodrigues *et al*, 2009). These areas exhibited temporal signature similar to herbaceous- shrubby vegetation described in Loebmann *et al*. (2012).

Differences between EVI2 time series of these PPAs (2 and 3) were about the surrounding non-forest physiognomies which can influence the temporal signature (Lambin & Linderman, 2006).

The PPA 4 had more than 50% of MODIS pixel occupied by soybean plantation (figure 3.4). The one exhibited short phenological cycles (about 3 months) which the senescence stage explained the EVI2 time series lines (Kuplich *et al*., 2013). The PPA 4 spectro-temporal pattern was similar to plantation (Figure 3D).

The climate factors could affect the vegetation development, mainly on its phenology. We found positive correlation only for PPA 1 for all years, concerning the relation between EVI2 times series and rainfall index. We observed advances in natural sucession based on its environmental assessment.

In relation to cumulative EVI2, the EVI2 values from 2003 to 2012 allowed grouping the PPA and reference areas in classes (figure 4B). The PPA1 temporal signature was next to Semideciduous Forest, while the PPA 4 got close to the plantation. On the other hand, PPAs and the reference areas remaining (pasture and Cerrado) of cumulative EVI2 overlapped, which were explained by the spatial heterogeneity. We also observed that there are the following classes, in decreasing order of EVI values: Semideciduous Forest, Plantation, Pasture, and Cerrado, according to Rosendo & Rosa (2005) and Anjos (2013). This technique was used by authors to distinguish areas of the Triângulo Mineiro.

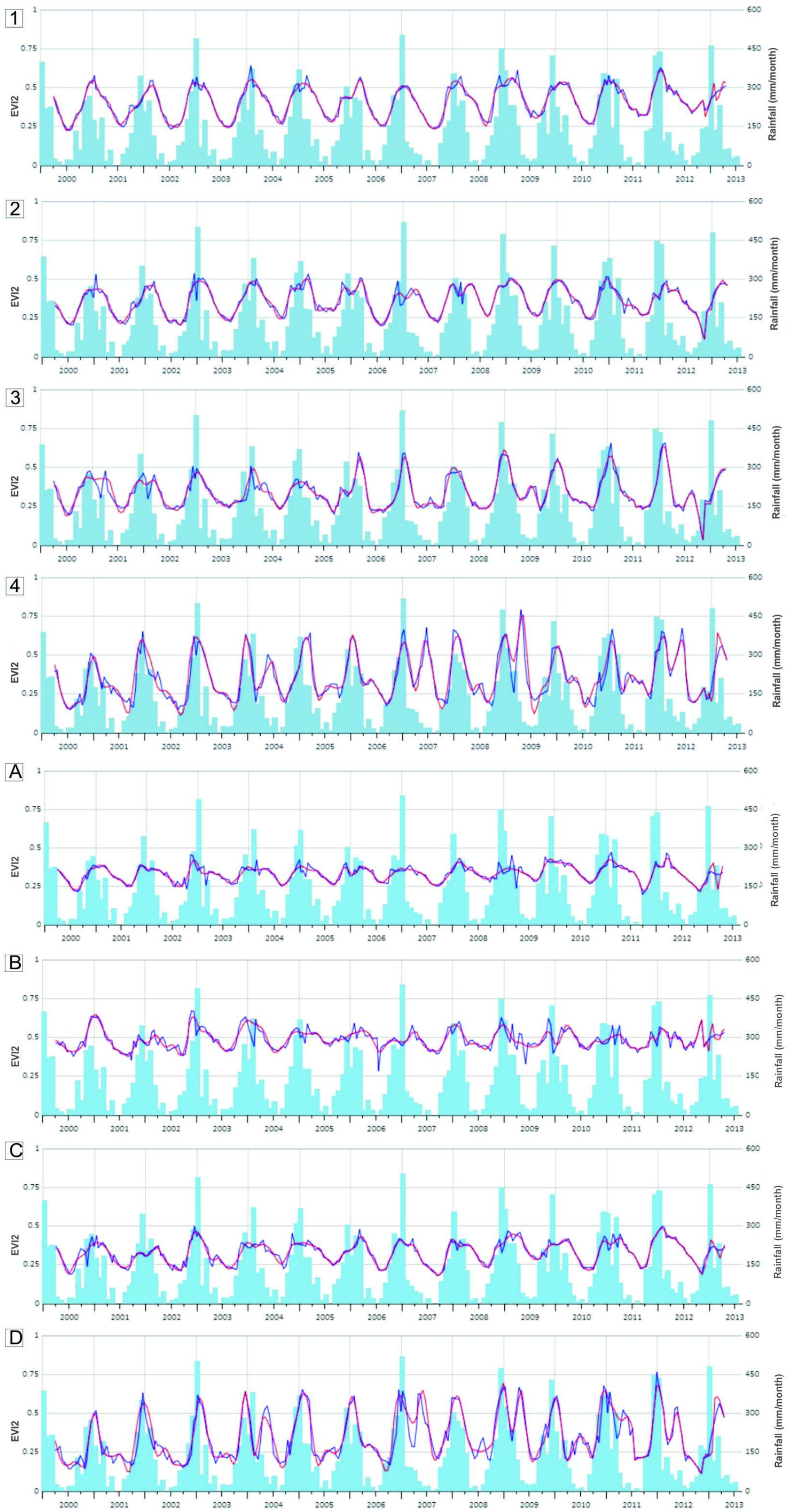

Fig. 3: Temporal signature of EVI2 without (blue line) and with wavelet (red line) of areas figured by the numbers from 1 to 4 for PPA and the letters A, B, C and D, referring to Cerrado, Semideciduous Forest, Pasture and Plantation, respectively. The histograms show the rainfall in the areas.

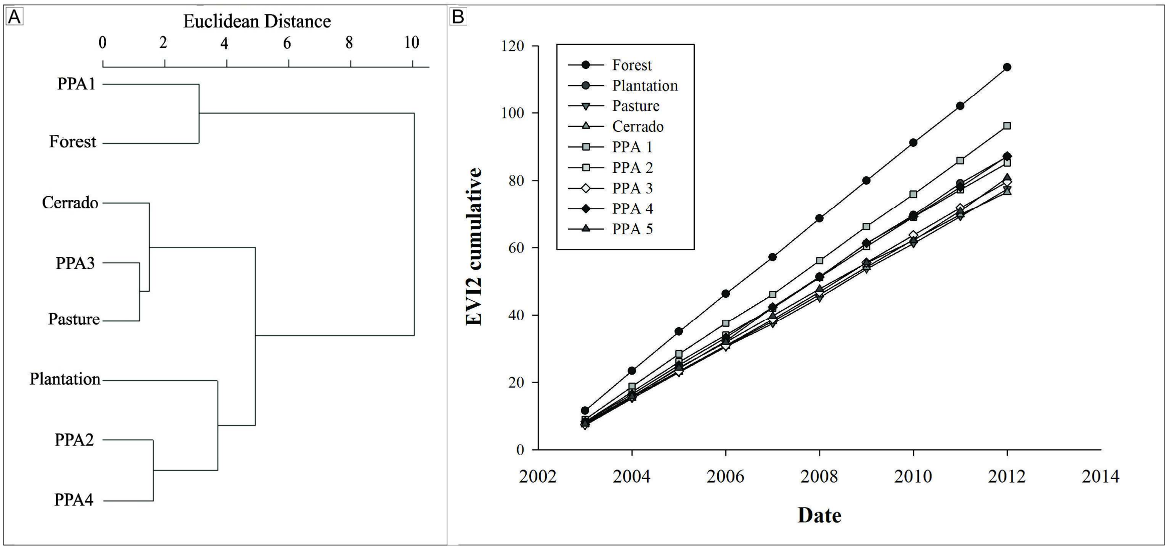

Fig. 4: Comparison between classes: (A) The dendrogram showed the clustering analysis and the EVI2-MODIS variables (B) Cumulative EVI2 of the reference areas and of the PPAs for the years from 2003 to 2012.

The affirmation above was confirmed by the clustering analysis. The test showed the relationship between groups analysing the PPA surroundings region and their similarity to reference areas (figure 4A). However, we observed less similarity between reference areas and PPA with greater spatial heterogeneity in surroundings, which the ones had different land use (PPA2 and PPA 3).

Discussion:

The parameters of environmental assessment represented the environmental aspects of each PPA showing their current stage of conservation after 9 years. The RAP was able to observe and control the degradation. Although the family agriculture is predominant in Southern of Minas Gerais, the presence of the remaining native vegetation still being essential for triggering or accelerating the ecological restoration process of degraded areas, which its enable natural regeneration conduction and the ecological processes reestablishment (Martins, 2014).

Although the PPAs pixel were heterogeneous, by means of their cumulative EVI2, it was possible comparing reference areas with them, and to visualize the class on which PPA was getting close or becoming similar (Rosendo & Rosa, 2005; Anjos *et al*. 2013).

The time series analysis got partial information about the trajectory of ecological restoration process of PPA as well as the history of land use/land cover (LULC) provided by environmental assessment was essential. Furthermore, the reports provided the changes evaluate, which occurred over time, either the natural succession of PPA surrounding springs, or the advance of agricultural crops and/or pasture forward inland of PPA.

Conclusion:

The rapid assessment protocol is useful to determinate and assess the current condition of specific ecosystem and to enable change monitoring over time. Therefore, this RAP may establish cheaper basis for the ecological restoration programs, and assesses limiting factors toward the monitoring process of PPA in different degrees of degradation.

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