Effects of landscape fragmentation in the Protected Area of the Parque Estadual de Campos do Jordão - SP

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Abstract. *Tropical forest remnants play an important role as carbon sinks. Landscape-scale studies are important to understand how landscape structure and its elements are related to patterns of carbon stocks and biodiversity. The results can contribute to improved management of protected areas that have been affected by planting of exotic tree species. In this work, we used landscape metrics and estimated the loss of carbon sequestration potential in newly formed edges in a scenario of removing of planted stands of various species of* Pinus *in a protected area in south-eastern Brazil. Our results showed that the removal of* Pinus *stands is expected to lead, at first, to a loss of carbon sequestration by native forest stands at the newly created edges, especially in the first five years following the removal of the stands with exotic tree species.*

1. Introduction

Large expanses of natural environments have been negatively affected by land use changes such as the expansion of agricultural activities and urban development in the last century. In Brazil, one of the consequences of these processes has been the reduction of the area of primary forest cover, forest fragmentation and habitat loss [Laurance, Vasconcelos, Lovejoy, 2000, Metzger, 2009, Silva Junior et al., 2018].

According to Moraes et al. (2015), the fragmentation process produces a heterogeneous effect on the landscape, characterized by distinct units or elements such as matrices and forest remnants of different sizes. The spatial distribution of landscape elements is the result of the combination of the original land cover an its historical change via land use.

The Atlantic Forest biogeographic domain has been severely affected by fragmentation and degradation [Joly, Metzger and Tabarelli, 2014]. Of its original 150 M ha forest cover [Ribeiro et al., 2009], only 28% remain [Rezende et al, 2018], indicating a large historic loss of carbon stocks. Currently, the Atlantic Forest is characterised by the dominance of isolated remnant fragments smaller than 100 ha, many being of secondary origin, in their initial and medium stages of succession [Metzger et al., 2009]. The most common land cover types surrounding the forest remnants are pastures, agricultural fields and urban areas. The Atlantic Forest is a biodiversity hotspot [sensu Myers et al., 2000] and it hosts one of the most diverse endemic rainforest biota in the world [Myers et al, 2000 and Laurence, 2009].

The severely fragmented nature of the Atlantic Forest implies that the fragments are in different stages of regeneration from disturbance [Ribeiro et al., 2009 and Tabarelli et al., 2012]. Importantly, secondary forests, planted or naturally regenerating have an increasing role as a potential sink of atmospheric carbon [Kamiuto, 1994, Villanova et al., 2019], and because of that, it is rapidly becoming one of the main poles of attraction of international investments.

To ensure a balance between the biodiversity conservation and the continued provision of various ecosystem services, such as food production, climate change, the regulation of the water and carbon cycles, careful land use planning is necessary. Carbon sequestration from forest regeneration could be assertive strategy to accomplish the ambitions forest conservation and restoration programs planned for the coming years, such as 200Mha of forest landscape restoration commitments as part of Bonn Challenge. For this, understanding how landscape configuration is related to the transfer of energy and matter among landscape units and, in turn, to modulating the dynamics of plant and animal communities is necessary [Lovett et al., 2005, Turner, 2005].

Applying landscape ecology metrics, landscape structure and its elements can be described quantitively. The application of metrics may be used for management planning (reconfiguring landscape structure for water yield regulation), or in conservation management planning (e.g., creation of corridors, exploring the impact of the removal of stands of exotic plant species) as they offer strategic guidelines [McGarigal, Marks, 1995]. Landscape metrics have been used to quantify changes in land use and land cover such as (i) its spatial relationship structure between ecosystems and/or elements present therein, (ii) its ecological function and the interactions among spatial elements, and (iii) change in the structure of the elements as a whole [Scalioni et al, 2018, McGarigal, Marks, 1995]. There are conservation unit-level studies on the detrimental effects of fragmentation (Putz et al., 2014) and land use change (Rosa et al., 2021) on AGB stocks, but none of them consider the first years impacts of landscape reconfiguration.

In this work we described the current landscape of Parque Estadual Campos do Jordão, São Paulo state, Brazil, and explored a scenario of the contemporaneous removal of ca. 1500 ha of *Pinus* and other exotic tree plantation, to estimate the carbon sequestration loss in newly formed edges after exotic species removal.

2. Materials and Methods

2.1 Study area

The study was carried out in the Parque Estadual Campos do Jordão (PECJ), a designated protected conservation area (state park) of 8,341 ha in the Serra da Mantiqueira Protected Area (Figure 1). The PECJ was created in 1941 to protect the critically endangered plant species *Araucaria angustifolia* [Thomas, 2013]. In addition to this species, the PECJ is home to more than 800 species of vascular plants, 25 of which are listed as being under some level of threat.

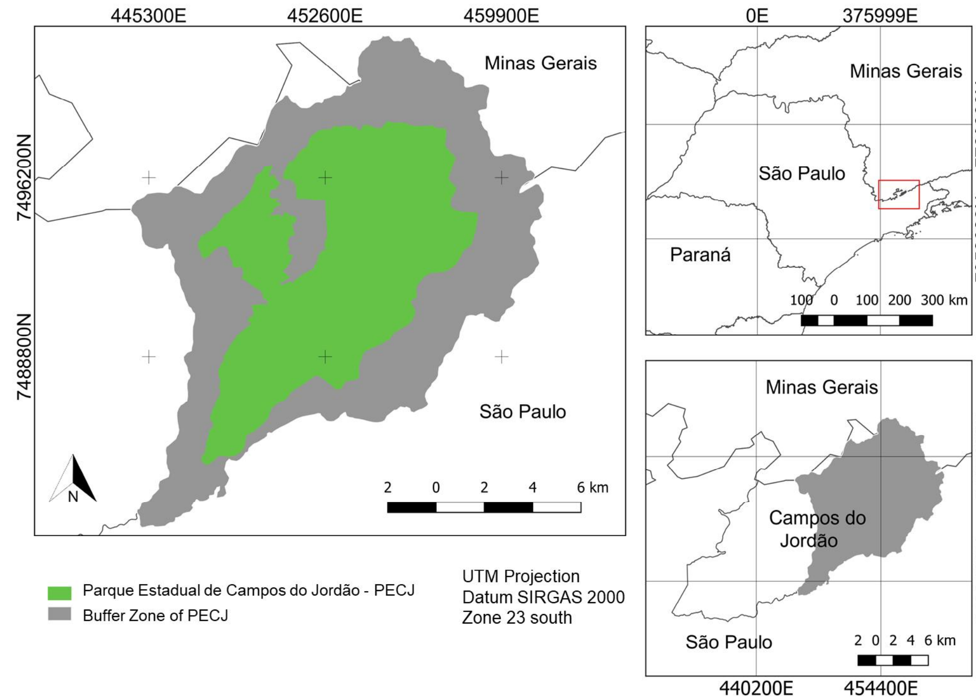

Figure 1 - Location of the study area Parque Estadual de Campos do Jordão, São Paulo State, Brazil.

The climate of PECJ is characterized by an average annual temperature of ca. 14.3ºC, total annual precipitation ranges between 1,205 to 2,800 mm [Fundação Florestal, 2015]. The elevation of the PECJ ranges from 1,030 to 2,007 m above sea level, and it is covered by mixed ombrophilous forests (tropical montane forest) with

Araucaria angustifolia. There are extensive areas covered by open grassy-shrubby vegetation, plantations of seven *Pinus* species, mostly of *P. elliotti* and *P. taeda* covering about 1080 ha [Fundação Florestal, 2015].

Historically, the Park underwent an intense deforestation process for extraction of wood for civil construction and there was livestock husbandry practiced. After the designation of the Park, it supplied firewood for the railways and in the late 1950s and early 1960s over 2000 ha was planted with *Pinus* species native to North America [Sampaio, Schmidt, 2013, Fundação Florestal, 2015].

2.2 Characterization of the landscape of the PECJ

A landscape analysis was performed by calculating landscape metrics based on the land use and land cover map (Figure 2) from the Park Management Plan [Fundação Florestal, 2015].

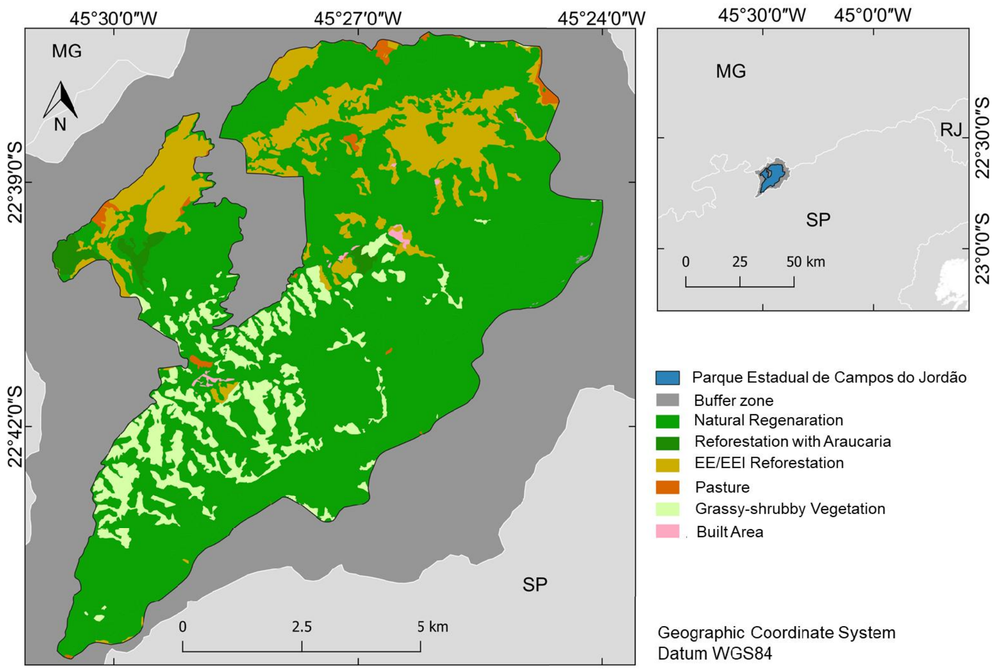

Figure 2 – Land use and land cover map of the Parque Estadual de Campos do Jordão (2015).

In the first step, a binary forest vs. non-forest map, based on the land use and land cover map from Fundação Florestal (2015) was created with spatial resolution of 30-m. Areas classified as “Regeneration”, “Reforestation with Araucaria” and “Reforestation EE/EEI” were considered as forest. The “Reforestation EE/EEI” class indicated the area with reforestation with exotic species/potentially invasive species. All the other classes were grouped as non-forest.

In the second step, landscape metrics were calculated by using the Morphological Spatial Pattern Analysis (MSPA) tool implemented in the open-access software GUIDOS toolbox from the European Commission's Joint Research Centre

[Soille, Vogt, 2009]. MSPA carried out an automatic classification by assigning each pixel to different fragmentation classes: (1) Edge: perimeter of the forest area, (2) Core area: innermost area of a forest fragment, (3) Island: disconnected portions of the fragments with no core area, (4) Perforation: inner edges, (5) Loop and (6) Bridge: connectivity metrics with no core area, but connecting forest fragments, (7) Branch: narrow extension of the fragment with no core area [Soille, Vogt, 2009].

From the MSPA analysis, the categories with no core area (island, perforation, loop, bridge and branch) were used to define edge for this work. An edge depth of 120 m was adopted after Silva Junior et al. (2018) and Vedovato (2016) for the subsequent calculation of the annual rate of lost carbon sequestration at newly formed edges.

2.3 Simulation of the contemporaneous removal of stands planted with exotic tree species

According to the Management Plan of the Park, areas currently planted with exotic species should be clear-cut and reforested with native species [Fundação Florestal, 2015]. The removal of patches of closed vegetation creates new forest edges. Forest edges suffer from the so-called edge effect (e.g., alteration of local climate, direct effect of wind speed, increased mortality tree rate) [Berenguer et al., 2014, Magnago et al., 2015, Laurance et al., 2018]. It has been shown that edges created during fragmentation suffer a reduction in their capacity to sequester carbon. To simulate the impact of the removal of all stands of exotic plantations on the capacity to sequester carbon by remaining native forest vegetation in the newly created edges, we substituted all original polygons of Reforestation EE/EEI for non-forest.

After reclassified the land use land cover map, the landscape metrics were recalculated in MSPA. Subsequently, applying map algebra, the reclassified map was subtracted from the previous MSPA analysis to identify the new edges. Additionally, the core and border area value for the newly generated map were updated.

To quantify the loss of potential carbon stock in the hypothetical newly edge areas, we used the method by Silva Junior (2018). The method approach is based on the tree mortality rate caused by edge effect along the following years. According to Silva Junior (2018), the annual non realised carbon sequestration in edges as compared with core areas of forest tends to zero after five years, as shown in Table 1. Also, we considered the aboveground biomass density map from Baccini et al (2012), as it has suitable spatial resolution for local scale analyses (30 m map)

Table 1 - Loss of carbon stock by age of forest edge

Age (year)	F_i	$f_i = F_i \ x \ 0,5 \ x \ 0,9$
1	0,233	0,010
2	0,069	0,003
3	0,033	0,001
4	0,019	0,001
5	0,013	0,001
6	0,009	0,000

Source: Adapted from Silva Junior (2018).

Non-realised carbon sequestration by age of the forest edge was calculated according to equation 1.

$$E_c = BAS \ x \ f_i \tag{1}$$

where, E_c is the lost (non-realised) quantity of the carbon stock per year, *BAS* is the above-ground biomass value estimated by Baccini et al. (2012), f_i is the annual rate of carbon loss in Mg per unit area.

3. Results and Discussion

The total area covered by forest corresponded to ca. 88% of the area of the PECJ, of which 75.3% (5500 ha) were classified as core area and 24.7% (1810 ha) as edge (Figure 3a). The contemporaneous removal all exotic species (1080 ha) resulted in creating 910 ha of new forest areas affected by the edge effect (Figure 3b). However, the proper management of these areas can contribute to the restoration of up to 1080 ha of forest, which has the potential to allocate about 0.1 Tg of carbon from atmosphere.

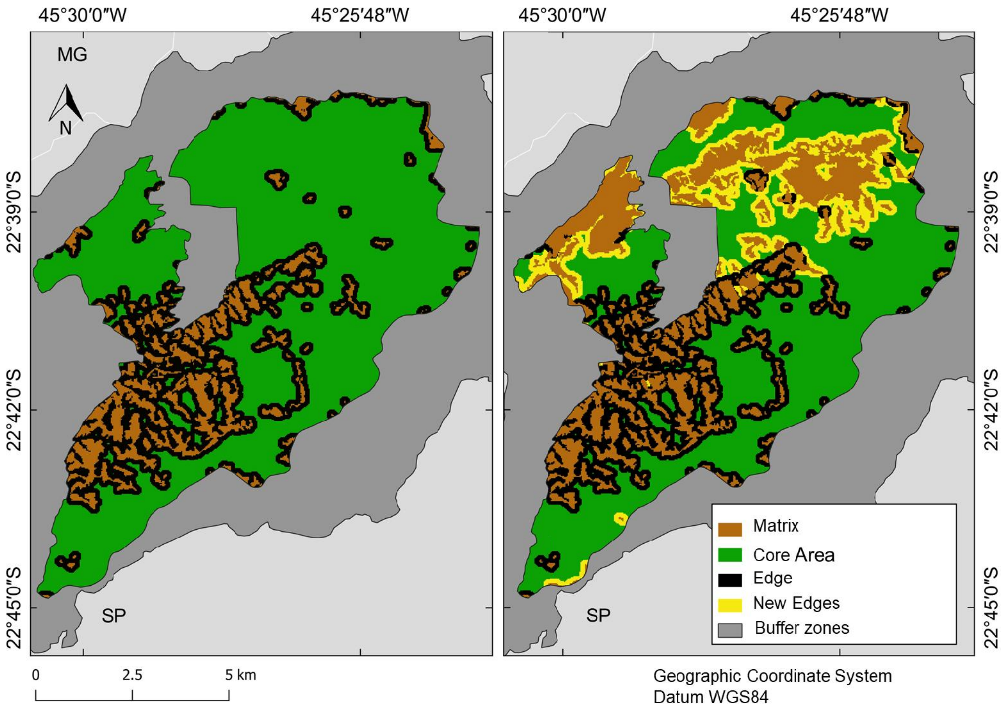

Figure 3 – Forest areas affected by the edge effect in the Campos do Jordão State Park under current land cover (A) and under the scenario of contemporaneously removing exotic species (*Pinus*, non-*Pinus* conifers and *Eucalyptus* spp).

The simulation of the carbon loss owing to edge effect showed that the PECJ could amount up to 0.38 Tg of carbon over six years after the removal of the exotic plantation. Most of the non-realised carbon sequestration (0.23 Tg C) would occur during the first year of the simulation, at an average rate of 17.8 ± 2.1 Mg ha^{-1}. After the fifth year, the annual loss would not be superior to 0.01 Tg C yr^{-1}.

Many protected areas in the Atlantic Forest in the state of São Paulo include areas planted with exotic species [Sampaio, Schmidt, 2014]. These species were planted by the state Forest Research Institute for experimental purposes with a view for evaluating their potential for plantation forestry. The presence of exotic species is undesirable in protected areas as can interfere with the integrity of native ecosystems [Bechara et al., 2013, Burgueno et al., 2013 and Sampaio, Schmidt, 2014] by altering the biology and chemistry of soils, causing change in forest structure and composition, and altering biotic relations [Richardson, Williams, Hobbs, 1994 and Richardson, 1998].

The removal of stands of exotic species from protected areas incurs a carbon cost by (a) the removal of biomass via harvesting, causing soil loss during harvesting operations and indirectly by creating forest edges, exposing them to edge affects, which will result in a reduction in carbon sequestration and carbon stock. With time these losses will be compensated by the regrowth of secondary forest stands, composed of native species. It has been estimated that secondary forests in the tropics contribute to a total accumulated carbon stock of up to 192 MgC ha-1 [Shimamoto, Botosso, Marques, 2014]. The benefits of native species regrowth go further than enhanced carbon sequestration, which is 40 times greater in naturally regenerated forest compared to planted forests [Lewis et al., 2019], it also contributes to recover and conserve biodiversity, enhance productivity and ecosystem resilience, and soil and hydrological stability [Sacco et al., 2020].

As our simulation results regarding to edge effect showed, clear-cutting plantation areas is expected to reduce temporarily the amount of carbon stock and carbon sequestered by the remaining forest. The newly exposed edges would receive increased exposure to radiation and higher temperatures, affecting the local microclimate, in addition to greater exposure to exogenous factors such as wind. Our results are based on the application of an empirical equation that we did not validate in our study area therefore the numerical values may not be accurate. Nonetheless, the potential carbon loss owing to edge effect will occur. Edge effects also negatively affect biodiversity [Laurance et al. 2000, Magnago et al., 2017]. To avoid or at least reduce the impacts that edge effects are likely to cause to biodiversity and carbon sequestration (and other ecosystem services that we have not quantified in this study) a potential practical solution could be the gradual substitution of these exotic planted areas, for example by applying thinning/selective harvesting to encourage natural regeneration before the final removal of the remaining individuals of exotic species. Minimising the negative impacts of removing invasive exotic species, will maximise in terms of both biodiversity and ecosystem services the benefits of restoring native forest cover in the PECJ and more widely in the Atlantic Forest.

4. Final considerations

Careful management of invasive and exotic species is required to minimise the impacts on carbon sequestration and other ecosystem services and maximise the benefits to biodiversity. We highlighted the importance of edge effects that clear-cutting could cause in terms of foregone carbon sequestration benefits. We recommend that targeted research, including academia and conservation and forestry practitioners explore management methodologies to minimize the impact of replacing stands of exotic species with stands of native species on ecosystem services and biodiversity. Integrated studies that combine ecosystem ecology and landscape ecology along with the quantification of the impacts of planned interventions on ecosystem services are recommended to assist local management units and to strengthen the knowledge base for environmental policies on restoring native vegetation and conserving ecosystem services.

5. Acknowledgement

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