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The use of species distribution models to predict the spatial distribution of deforestation in the western Brazilian Amazon

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ABSTRACT

The prevention of deforestation in rainforests requires the identification of where facilitating and mitigating factors will combine and increase the likelihood of deforestation. This approach, which relates a geographic space with an environmental space of factors to predict where new deforestation will occur, is very similar to the approaches used to predict species distributions. Thus, we believe that deforestation can be treated as a "species" and that its future occurrence can be determined using species distribution models.

The objective of this work is to test the efficiency of species distribution models in predicting the potential areas of deforestation in a region of the western Amazon. We analyzed five different areas in the arc of deforestation. For each area, we ran the MaxEnt model in six different experiments to determine the boundaries of the probability distributions.

Potential areas identified using the different models of MaxEnt were very effective in predicting deforestation areas. The models that used only previous deforestation density were less effective than the models that included functional variables.

In four of the five areas, 80% of the new deforestation occurred in the area predicted by the models. These models were more effective than the business-as-usual (BAU) and governance (GOV) model scenarios described using the DINAMICA-EGO platform by Soares-Filho et al. (2006).

Species distribution models are a valuable tool for determining potential areas of future Amazon deforestation. The use of these models arises as support to efforts to conserve tropical forests and identify critical locations where command and control actions against deforestation can be most efficient.

1. Introduction

The Amazon forest contains countless natural products of pharmaceutical importance and provides various vital ecological services, such as soil conservation and water regulation (Fearnside, 2006). Despite the importance of the Amazon, the forest has been deforested, burned, fragmented and over-exploited at unprecedented scales (London and Kelly, 2007). Brazil, which contains most of the Amazon rainforest, is a leader in tropical deforestation, with an average rate of 23,000 km^2/year between 2005 and 2010 (FAO, 2010).

The enforcement of regulations and control measures is intended to decrease the deforestation rate, but these measures are palliative because the environmental damage has already been done (Souza et al., 2013). Thus, the prevention of environmental damage is as important as the enforcement of laws. To enable effective preventive actions, the consideration of certain factors is necessary. First, information derived from satellites (Asner et al., 2006) must be used to locate and quantify the environmental damage. Second, the factors and actors responsible for deforestation must be identified and located (Fearnside and Barbosa, 2003) so that the causes can be addressed. Third, the determination of land ownership (Fearnside, 2006) is important for the determination of responsibility for the damage and the recovery the fine and restoration. Finally, modeling of deforestation scenarios (Soares-Filho et al., 2004) enables us to predict which regions will experience an increase in the deforestation rate.

Since the 1990s, several studies have produced spatially explicit models to simulate the dynamics of deforestation (Laurance et al., 2001; Soares-Filho et al., 2004). The DINAMICA-EGO package developed by Soares-Filho et al. (2002, 2003) is a platform with which

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to develop tools and methods to be applied to studies of landscape dynamics and environmental modeling. DINAMICA-EGO was the platform used by Soares-Filho et al. (2006) to create a model to predict the amount of Amazon deforestation up to the year 2050. This model, based on the *Weights of Evidence* method, was used to understand the effects of spatial variables on deforestation and was run under eight different scenarios. These eight scenarios represent a gradient of environmental law enforcement levels. At one extreme of this gradient is a conservative scenario (GOV) that considers the major paved roads and the current deforestation trends across the Amazon, with the perspective that deforestation rates will decrease as governance is gradually increased. Furthermore, in this conservative scenario, deforestation does not surpass 50% of private areas, with a minimum of 15% of these private areas deforested, and the network of protected areas is assumed to be expanded in the Brazilian Amazon. The other extreme of the gradient involves a scenario with the condition of business as usual (BAU), which considers that the deforestation rate will be the same as the rate of 1997–2002 with the additional impact of paving major roads. Furthermore, in the BAU scenario, deforestation cannot surpass 85% of private areas, with a minimum of 50% of these private areas deforested, and the network of protected areas is assumed to lose up to 40% of its natural vegetation.

These results demonstrated that this model is a powerful tool with which to identify possible advances arising from new methods of modeling deforestation. Current attempts conducted by the Brazilian government to determine where new deforestation will occur in the Amazon are primarily based on previous deforestation events using simple spatial interpolation (kernel analysis) (IPEA, 2011). Here, we evaluate a novel approach to predicting future deforestation using recent advances in ecological modeling. We consider that the locations with a greater chance of future deforestation are likely associated with a set of conditions; this process resembles the approach used by species distribution models (SDMs) (Elith and Leathwick, 2009). This approach includes numerical tools that combine species occurrence with environmental parameters to predict the distribution of species across landscapes, in some cases requiring extrapolation in space (Elith and Leathwick, 2009). The novelty of our approach is its treatment of a deforestation area as a species and its use of an SDM to predict the potential distribution of deforestation. For this approach, we consider that environmental conditions, accessibility and socioeconomic variables affect the behavior and activity of the actors involved in deforestation (e.g., loggers, farmers, gold miners, and ranchers). We consider that variables representing socioeconomic and political forces that facilitate or restrict the process of deforestation must be called “functional variables” rather than “environmental variables,” the term commonly used in the original SDM approach.

There is extensive literature regarding the causes and factors affecting deforestation (Pfaff, 1999; Margulis, 2003; Fearnside, 2008). An analysis of these studies suggests the existence of two sets of variables that determine the local occurrence of deforestation. First, certain variables are simply related to the fact that deforestation develops as a spatial process. Thus, the presence of a deforested area adjacent to an area currently not cleared can be a strong predictor of the likelihood of the area’s future deforestation (Soares-Filho et al., 2006). Additionally, there are variables that affect the occurrence of deforestation, such as socioeconomic processes that are linked to market availability, the accessibility of timber markets, and difficulty of surveillance. In this study, these variables are called functional variables and include the distance from roads (Laurance et al., 2001), the presence of livestock (Margulis, 2003), the expansion of agriculture (mainly soybeans) (Martinelli et al., 2010b), and conservation units (Nepstad et al., 2009).

The objective of this work is to test the efficiency of species distribution models in predicting the potential areas of deforestation in a region of the western Amazon. To achieve this objective, we developed 30 different models, alternating the functional variables in five regions of study, and tested the efficiency of these models in determining the potential areas of future deforestation, particularly compared with other models with the same purpose, as the proposed by Soares-Filho et al. (2006). Thus, we tested two hypotheses. First, models for different parts of the Amazon that are built only with variables that represent the spatial interpolation of known deforestation points are less efficient than models based on functional variables. Second, species-distribution models can be equally or more effective than models already established to identify areas of potential new deforestation.

2. Materials and methods

2.1. Study area

We analyzed five different areas of the Amazon (Fig. 1), totaling 515,374 km^2, in the states of Acre, Mato Grosso, Pará, Rondônia and Amazonas, which are mostly located inside the deforestation arc. This arc is the region where the loss of natural vegetation has occurred most rapidly and disorderly over the last 50 years, representing the most aggressively colonized edge of the rainforest (Durieux et al., 2003). Each of these regions is at the limits of the jurisdiction of the regional IBAMA offices. IBAMA (the Brazilian Institute of Environment and Renewable Natural Resource) is the main agency responsible for environmental surveillance in Brazil. The names of the study regions represent the locations of the IBAMA offices as follows: Rio Branco (155,000 km^2), Alta Floresta (61,596 km^2), Apuí (176,785 km^2), Novo Progresso (38,170 km^2) and Porto Velho (83,802 km^2) (Fig. 1). The study areas represent a microcosm of the situations encountered in the Amazon region, most notably the conversion of natural vegetation to livestock pasture. Soy monocultures are also present in the study areas as well as large infrastructure projects such as the construction of large dams, including Santo Antônio and Jirau near Porto Velho, and the creation and/or paving of major highways. Although these areas are located within the deforestation arc, the different land uses in these areas determine different levels of deforestation, with the loss of natural vegetation varying from almost 50% (Alta Floresta) to less than 5% (Apuí).

2.2. Occurrence of deforested areas

The occurrences of deforestation used as data were derived from the Deforestation Monitoring Program (PRODES) of the National Institute for Space Research (INPE), which provides information in vector and raster formats of the deforestation from 1997 to 2010. We trained the models using information from the year 2008 and tested these models with data from the year 2010. In the five studied regions, the PRODES system detected 7914 occurrences of deforestation in 2008. In that year, the numbers of deforestation occurrences was 1536 in the Alta Floresta region, 879 in the Novo Progresso region, 822 in the Apuí region, 2726 in the Porto Velho region and 1951 in the Rio Branco region.

We selected these years because changes in Brazilian environmental law that increased the punishment for environmental crimes and established the ability to seize equipment and goods found in illegally deforested areas were implemented in 2008 (Presidência da República, 2008). Furthermore, this new law created a public black list of persons and companies that committed environmental crimes, limiting the ability of these lawbreakers to