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Forest management for economical and ecological development in Legal Reserve areas in Brazil

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Abstract

In Brazil, the Federal law 12.651/2012 requires allocation of at least 20% (excluding the Legal Amazon Region) of rural properties to form Legal Reserve areas (RL's) – destined to ensure the sustainable economic use of natural resources and also assist in the rehabilitation and preservation of ecological and biodiversity processes. More than just a legal compliance, its deployment is a powerful instrument to promote the planting of new forests, planned for both purposes. This study was carried out to develop forest growth models, thereby determining which species are more profitable to compound ecologically and economically sustainable wood production systems for the Cerrado (Brazilian savanna) and Atlantic Rainforest biomes. Representatives of the governmental, technical and scientific sectors were involved in this project to become forest management in RL's illegible. Based on data collected from several forest restoration projects, we developed growth models for 41 species to estimate timber production at any age. The group of 41 species is quite heterogeneous under several aspects, e.g. growth, environment, silvicultural experience and forest market. Considering this, our models take into account environmental variations among sites to estimate growth, e.g. temperature, precipitation, altitude and soil moisture. Additionally, the models were quite flexible considering natural variations within sites based on modeling Weibull distribution parameters for each species. From an economic standpoint, we found RL's provided economical benefits for landowners with great feasibility. From an ecological standpoint, using natural species for forest restoration increases structural and biological complexity. The relevance of exploring native species in RL's lies in their contribution to reconciling ecological and economic aspects and thus effectively relativizing the antagonism between the preservation of native forest resources and income generation.

Keywords: Legal Reserve areas; Forest production modeling; Native species.

Introduction

Reforestation is a potential strategy to reduce the logging pressure on remnant natural forests, while considering local socio-economic interests (Paquette and Messier 2010). Recent research has emphasized the potential advantages of native instead of exotic species, planted in mixed stands rather than in monocultures (Piotto et al. 2010). Mixed species plantations may lead to higher stand-level productivity compared to monocultures as a consequence of positive ecological interactions among different timber species (complementarity, facilitation) (Erskine et al. 2006) and reduced negative impacts of insect herbivores and diseases (Jactel and Brockerhoff 2007).

The use of mixed-species plantations, or polycultures, points to what are probably the best prospects for plantation forestry in the Anthropocene: to proactively design plantations to produce the combination of desired outputs, such as key ecological services, while simultaneously delivering many other important social and economic benefits (Paquette and Messier 2010). Unfortunately, despite continuing calls from a wide range of advocates for mixed-species plantations, only little of present industrial plantations are polycultures (Nichols et al. 2006). Mixed-species plantations are often considered to be non-viable, operationally or economically, by many in the forestry industry. Long-term trials that are well replicated in time and space (Srivastava and Vellend 2005) and operational-scale demonstration sites that collect economic, social, and environmental data – as well as conventional productivity data – are greatly needed (Nichols et al. 2006).

There is a clear necessity to provide information on mixed-species forest growth and economical benefits, so boosting the use of native species for wood production in Legal Reserve areas in Brazil for both economical and ecological purposes. In this context, we seek to develop growth models for 41 native species that are commonly used in forest restoration projects in the São Paulo State in Brazil, including environmental variables in models to spatial modelling. Additionally, we investigated the economical performances of the species by building a discounted cash flow for each county of the São Paulo State. On these cash flows, we took into account the regular operational costs, regular prices of each wood product, and possible combinations of species considering ecological aspects.

Methodology

We compiled information from tree diameter and tree height measurements carried out in areas of forest restoration in the São Paulo State by the Instituto Florestal, Pederneiras garden, Embrapa Florestas and the project “Sequestro de Carbono” of the CESP (Companhia Energética de São Paulo). We used information of diameter at breast height (DBH) at different ages for each species. Measurements were derived from different areas throughout the state for measuring the environmental variability. Each restoration project lies in different treatments with different tree spacing, silvicultural treatments, environmental characteristics and objectives for restoration.

Data analysis and growth modelling

We developed growth models to predict DBH based on climatic variables to modeling the variability influenced by environmental factors, such as evapotranspiration, Thornthwaite Moisture Index, average temperature in the coldest month, annual average temperature, average temperature in the warmest month, annual average precipitation, average precipitation in the rainiest month and average precipitation in the driest month. These climatic variables were modeled and estimated in a 100-meter resolution by Alvares et al. (2013). Climatic variables can be more easily obtained at broader scales comparing to other variables, such as soil properties, tree competition and genetic heritability, so climate was preferred rather than these other variables.

The DBH modeling was based on linear models using age and climatic variables. We tested every possible combination between the variables with different exponents keeping the linearity of the model, but not repeating any variable or highly correlated variables in the same equation in order to avoid multicollinearity problems. Models were fitted by ordinary linear least squares. The Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and graphic analysis were used for model comparisons. Additionally, we developed models to predict height based on DBH using the same data sets. Height and DBH were also used to volume prediction for each species using allometric equations specifically developed for cerrado, semi-deciduous and ombrophilous forests in the São Paulo state (Nunes, 2013). Modeling was performed using the software R (R Development Core Team 2012), with the lm function.

We performed diameter distribution modeling to predict the range of diameter and how variation between minimum and maximum diameters may occur at any environmental and silvicultural condition. We used the Weibull distribution, firstly proposed by Bailey and Dell (1973) for diameter class distribution, which includes both shape and scale parameters as a probability density function.

From the diameter distribution we can predict different scenarios of production under different conditions for economical estimative. We could simulate several alternatives of thinning sequences associated to the product prices in a cash flow analysis to find out the best options to each region.

Criteria and performance of economical aspects

We collected information on costs and wood prices to compose our database for evaluating the economical performance. After choosing the best thinning sequences for each species, we did one cash flow for each possible combination of two commercial species for each one of the 1273 sub-region of the São Paulo state. Furthermore, we calculated the incomes from yield curves considering the climate data of each county. Thereby we had 12 thousands of feasible cash flows for the sub-regions. Results were ranked according to the internal rate of return and the net present value financial indicators. The best cash flows of each county were sent to a database to compose a set of information about forest restoration process. The database is now an important source of information to support state policies.

Results and discussion

We developed equations for 41 species (Table 1) to estimate DBH based on age and climatic variables. Precipitation and evapotranspiration were the most common climatic variables included in the models because of the high correlation between these variables and DBH in the state of São Paulo in Brazil.

Table 1: Models to predict DBH at any age using climatic variables in the São Paulo state in Brazil.

Species	Allometric equation

Araucaria angustifolia (Bertol.) Kuntze	DBH = exp (0.7752 + 0.8864 ln(Age) - 0.0009 Altit)
Anadenanthera peregrina (L.) Speg.	DBH = exp (2.6387 + 0.7679 ln(Age) - 0.0074 Max precip)
Anadenanthera colubrina (Vell.) Brenan	DBH = exp (2.5072 + 0.5514 ln(Age) - 0.0008 Tot precip)
Aegiphila sellowiana Cham.	DBH = exp (-1.09004 + 0.92942 ln(Age) + 0.03031 Total precip0.5)
Albizia niopoides (Spruce ex Benth.) Burkart	DBH = exp (-0.283168 + 0.904419 ln(Age) + 0.002501 Max precip)
Astronium graveolens Jacq.	DBH = Age *exp (2.9741916 - 0.4339698 ln(Age) - 0.0022106 Evap)
Balfourodendron riedelianum (Engl.) Engl.	DBH = exp (0.961962 + 0.7583648 ln(Age) - 0.0007773 Evap)
Calophyllum brasiliense Cambess.	DBH =exp (-1.0227 + 0.8474 ln(Age) + 0.0003 Total precip + 0.0003 Evap)
Citharexylum myrianthum Cham.	DBH = exp (0.3959 + 1.1516 ln(Age)0.5 + 0.0027 Max precip)
Cordia trichotoma (Vell.) Arrab. ex Steud.	DBH = exp (1.6421 + 0.6632 ln(Age) - 0.0007 Evap)
Cariniana estrellensis (Raddi) Kuntze	DBH = exp (-0.1813807 + 0.8836698 ln(Age) + 0.00023 Total precip)
Cecropia pachystachya Trécul	DBH = exp (2.3988453 + 0.4456021 ln(Age) - 0.0005828 Total precip)
Cedrela fissilis Vell.	DBH = exp (-0.1960824 + 0.7694688 ln(Age) + 0.0004222 Total precip)
Ceiba speciosa (A. St.-Hil.) Ravenna	DBH = exp (0.318027 + 0.844905 ln(Age) + 0.001761 Max precip)
Centrolobium tomentosum Guillemin ex Benth.	DBH = exp (0.2442322+0.6613192*ln(Age)+0.0003492*Total precip)
Colubrina glandulosa Perkins	DBH = exp (0.6673604 + 0.7561171 ln(Age) - 0.0004624 Evap)
Croton urucurana Baill.	DBH = exp (1.545106 + 0.404183 ln(Age) + 0.003902 Min precip)
Dipteryx alata Vogel	DBH = exp (-1.3674 + 0.7520 ln(Age) + 0.0012 Evap)
Plinia edulis (Vell.) Sobral	DBH = exp (4.8279 + 1.7013 ln(Age) - 0.0039 Evap0.5)
Eugenia uniflora L.	DBH = Age *exp (0.160812 - 0.205127 ln(Age) - 0.001483 Max precip)
Genipa americana L.	DBH = exp (2.2236 + 0.6294 ln(Age)2 - 0.0009 Total precip0.5)
Guazuma ulmifolia Lam.	DBH = Age *exp (1.484376 - 0.544538 ln(Age) + 0.003227 Min precip)
Hymenaea courbaril L.	DBH = exp (1.5258 + 0.0290 ln(Age)2 - 0.0002 Evap2)
Handroanthus heptaphyllus (Vell.) Mattos	DBH = Age *exp (1.3129839 - 0.3785007 ln(Age) - 0.0006883 Evap)
Handroanthus impetiginosus (Mart. ex DC.) Mattos	DBH = Age *exp (1.95965 - 0.33488 ln(Age) - 0.07629 Min temp)
Inga laurina (Sw.) Willd.	DBH = Age *exp (0.1807145 - 0.4156122 ln(Age) + 0.0005049 Total precip)
Inga uruguensis Hook. & Arn.	DBH = exp (0.1574556 + 0.7700984 ln(Age) + 0.0005275 Evap)
Jacaranda mimosifolia D. Don	DBH = exp (0.9762298 + 0.7994684 ln(Age) - 0.0007266 Evap)
Lafoensia glyptocarpa Koehne	DBH = exp (0.591166 + 1.032741 ln(Age) - 0.001886 Max precip)
Lonchocarpus muehlbergianus Hassl.	DBH = Age *exp (0.667438 - 0.49935 ln(Age) + 0.004632 Min precip)
Luehea divaricata Mart.	DBH = Age *exp (0.110281 - 0.41028 ln(Age) + 0.002127 Max precip)
Myracrodruon urundeuva Allemão	DBH = exp (0.5841 + 0.6969 ln(Age) + 0.0021 Thorn)
Maclura tinctoria (L.) D. Don ex Steud.	DBH = exp (0.4049928 + 0.902965 ln(Age) + 0.0002022 Total precip -

	0.000248 Altit)
Myroxylon peruiferum L. f.	DBH = exp (- 0.6607731 + 0.806327 ln(Age) + 0.0005086 Max precip)
Nectandra megapotamica (Spreng.) Mez	DBH = exp (0.430821 + 0.904655 ln(Age) - 0.001303 Max precip)
Peltophorum dubium (Spreng.) Taub.	DBH = exp (1.1282 + 0.8911 ln(Age) - 0.0006 Evap)
Pterogyne nitens Tul.	DBH = exp (1.0617 + 0.6786 ln(Age) - 0.0005 Evap)
Piptadenia gonoacantha (Mart.) J.F. Macbr.	DBH = Age *exp (1.128917 - 0.441737 ln(Age) + 0.004113 Min precip)
Poecilanthe parviflora Benth.	DBH = Age *exp (0.5939614 - 0.275399 ln(Age) - 0.0004177 Max precip)
Schinus terebinthifolius Raddi	DBH = exp (1.0809 + 0.4878 ln(Age) + 0.0024 Min precip)
Trema micrantha (L.) Blume	DBH = Age *exp (1.5217107 - 0.6221079 ln(Age) + 0.000183 Total precip)

Based on the growth rates for the species in Legal Reserve areas in the São Paulo state and the volumetric distribution throughout the state we could perform economical simulations. Considering the best cash flows for each of the 1273 sub-regions of the state, we found an internal rate of return average of 13% in real basis, which is considered a good return for any forest activity. Despite having a high return, the plantation must have available funds from government. To recover 618 thousand hectares in the Legal Reserve areas in the São Paulo state we need to invest around 4 billion dollars in next 10 years.

However, the expected returns are much better than the returns we usually have now from those areas. We compared the current annual gross margin based on livestocks to the annualized net present value from the new forest plantation for each sub-region. We found that, on average, the new forest plantation would be 2.72 times better than the current.

We can see in the Figure 1 that in 95% of the area would have better profits than we have nowadays in the current land use. In 70% of the area, the returns would be more than a double that the returns we have today.

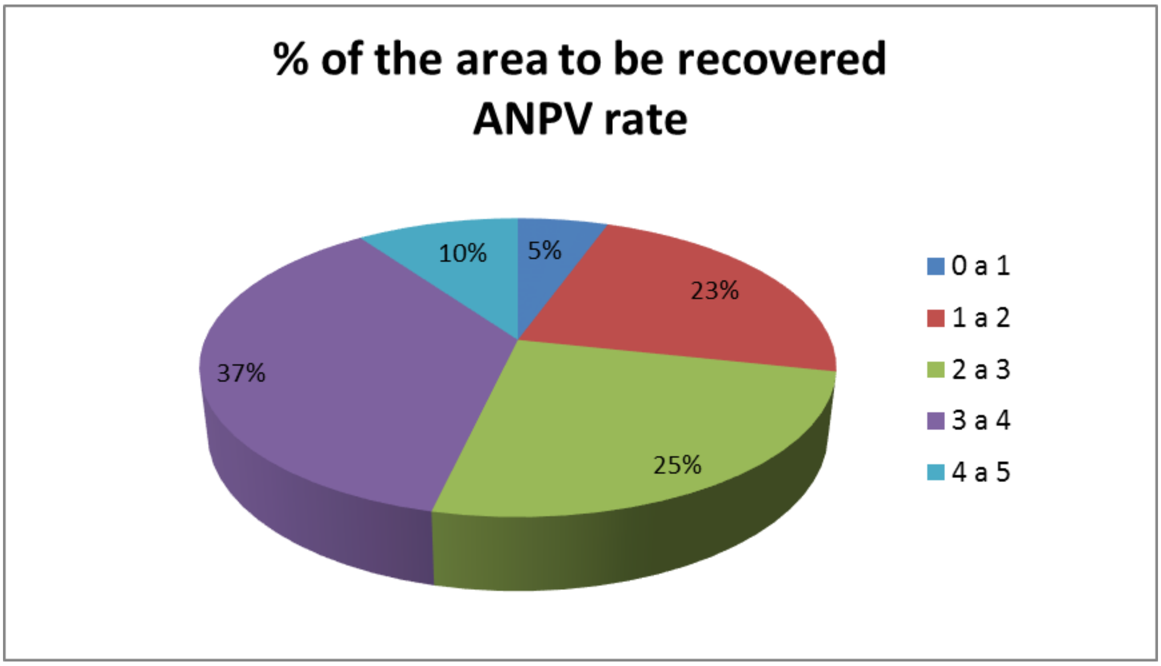

Figure 1: Annualized Net Present Value (ANPV) compared to annual livestock's gross margin of each sub-region.

The best cash flows were derived from the combination of five wood species: *Peltophorum dubium* (Spreng.) Taub, *Anadenanthera peregrina* (L.) Speg., *Cordia trichotoma* (Vell.) Arrab. ex Steud., *Myroxylon peruiferum* L. f. and *Citharexylum myrianthum* Cham. Continuous studies in search of promising species has extended the possibilities of combination of species for planting in the state. By preliminary studies, we have found more potential species to increase the variety and ensure profitability planting native species in the state.

Conclusions

The São Paulo state is diverse in forest types, including Cerrado, Semideciduous forests and Rainforests. Combination of species for reforestation aiming at economical and ecological benefits must consider environmental characteristics of each region as some species will be more productive in some areas than others. Planting forests can be more profitable than livestocks in a majority of areas in the state, bringing ecological benefits inherent to a more complex ecosystem.

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