Ecological Modelling 297 (2015) 118–125

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Assessing size–class dynamics of a neotropical gallery forest with stationary models

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ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form 2 October 2014
Accepted 5 November 2014
Available online 27 November 2014

Keywords:
Forest growth model
Matrix model
Riparian forest
Stationary model
Transient dynamics
Tropical forest

ABSTRACT

We used stationary matrix models to assess size–class dynamics of a protected neotropical gallery forest in Central Brazil, and tested their predictive capacity for different calibration periods. Data series comprised of all trees (with diameter $\geq$ 10 cm) registered in 151 (10 m $\times$ 20 m) permanent plots in the years of 1985, 1988, 1991, 1994, 1999, 2004, and 2009. Demographic and diameter growth rates fluctuated, and recruitment slightly decreased after 1991. All models produced reliable ($P > 0.05$) short-term projections ($\leq$10 years). However, models calibrated before 1991 produced unreliable >10-year projections. The model calibrated over the 1991–1994 period reliably predicted size–class structure after 5 consecutive 3-year simulations (15 years). Results show that short-term (10-year) size–class structure of protected neotropical rainforests can be reliably predicted using stationary matrix models; and that predictions are slightly sensitive to the calibration period. Although stand dynamics were variable and affected by environmental stochasticity, size–class structural dynamics remained close to constant after 1991, since all projections from stationary models calibrated after that year were similar to the observed data ($P > 0.05$). This indicates that, under the recent levels of natural disturbances, the forest has maintained stability in the size–class dynamics.

1. Introduction

Size–class matrix models can reveal important information on how forests behave under certain conditions (Keyfitz and Caswell, 2005) and have extensive application in forestry (see Liang and Picard, 2013). When calibrated on undisturbed forests, they help evaluate sustainability of particular harvesting regimes (Gourlet-Fleury et al., 2005). Stationary models (fixed-parameter models) assume transition probabilities are constant over time. This assumption is evidently false, because size–class parameters do change over time and are, in fact, density-dependent (Buongiorno and Michie, 1980). This explains the widespread application of density-dependent models (variable-parameter models) for forestry applications (Hao et al., 2005; Lin and Buongiorno, 1997; Orois and Soalleiro, 2002; Solomon et al., 1986; Zhao et al., 2005). Although the stationary assumption compromises long-term predictions, stationary size–class models are useful tools for forest management and conservation.

Keyfitz (1972) distinguished the terms forecast and projection. The former predicts what will happen in the future, whereas the latter describes what would happen under certain conditions. Forecasts can be unrealistic, but projections provide valuable information about present conditions of the forest, and the populations experiencing them. A powerful way to study the present conditions is to examine their projected consequences, if model parameters (mortality, growth and recruitment) remain constant. Demographic projections are particularly revealing because they integrate the impact of environmental conditions on vital rates throughout the life cycle. Knowing size–class parameters under given circumstances conveys a great deal of biological information about those circumstances (Keyfitz and Caswell, 2005).

Stationary models for size–structure projections are widely used for tropical forest management (Bruner and Moser, 1973; Buongiorno and Michie, 1980; Picard et al., 2007, 2009). However, little is known about multiple or long-term forecasts from these models, and how the reliability of predictions changes with calibration period. Most published models calibrated for natural

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http://dx.doi.org/10.1016/j.ecolmodel.2014.11.009
0304-3800/

tropical and sub-tropical forests have relied on few measurements and, therefore, projections could not be tested *ex post* against observed data (Pulz et al., 1999; Spathelf and Durlo 2001; Teixeira et al., 2007). Besides, the few studies comparing the projected and the observed size–class distributions tested only for short-term single projections (Austregésilo et al., 2004; Vasconcelos et al., 2009).

The present study is based on seven measurements of a well-protected neotropical gallery forest over a 24-year period. The two main objectives are: to test the predictive capacity of stationary size–class models, based on different calibration periods, for single step and multiple-step projections, by validating model projections against field data; and to assess size–class structure dynamics based on the analysis of these models and their projections.

2. Methods

2.1. Study site

Gallery forests are riparian corridors of non-deciduous tropical forests that act as buffer zones protecting rivers. In the Brazilian savannah biome, called Cerrado, they connect the world's two largest neotropical forests, the Amazon and Atlantic Forest (Oliveira-Filho and Ratter, 1995). The Gama stream gallery forest covers 64 ha in the East-Central region of Brazil, near the city of Brasília (≅16° S, 48° W) at an altitude of 1100 m. The forest is surrounded by campo limpo (natural dry grassland) vegetation, with an abrupt transition between these vegetation types (Fig. 1). The topography undulates gently, and the soil is well drained, dystrophic, with high aluminum saturation, and low nutrient concentration.

Köppen's (1900) classification categorizes the climate as Aw, with rainy summers and dry winters. Mean annual rainfall between 1984 and 2009 was of 1392 mm, with a mean annual temperature of 22 °C. Environmental data registered close to the study area, at the Brazilian Institute of Geography and Statistics' Ecological Reserve (RECOR-IBGE), revealed annual precipitation cycles with alternate periods of high and low annual precipitation. The period 1991–1994 departed from this trend and exhibited higher-than-average annual precipitation each year. Variations in mean annual temperatures were also observed, with a temperature increase trend after 1991 (Fig. 2).

A total of 52 families and 105 tree species were found in 1985, considering trees with diameter at breast height (dbh) ≥ 10 cm. Species richness gradually increased to 112 species in 2009. Species abundance distribution was typical of tropical forests: in 1985 and 2009, a large portion of tree species had five stems or less per hectare (72.38% and 76.32%, respectively), and the 10 most abundant species comprised almost half of the total number of stems (47.71% and 48.50%, respectively). The five most dominant species in 1985, in terms of relative abundance and basal area, were

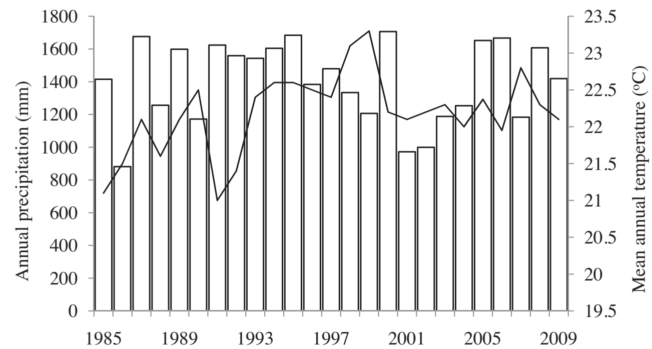

Fig. 2. Annual precipitation (mm) and mean annual temperature (°C) between 1985 and 2009 registered close to the study area, at the Brazilian Institute of Geography and Statistics' Ecological Reserve (RECOR-IBGE).

Lamanonia ternata Vell., *Copaifera langsdorffii* Desf., *Aspidosperma olivaceum* Müll. Arg., *Licania apetala* (E. Mey.) Fritsch, and *Metrodorea stipularis* Mart. (Felfili, 1995a). Most dominant species have kept a strong occupation since 1985. Tree density and basal area decreased, respectively, from 649.7 ind. ha^{-1} and 30.6 $m^2\,ha^{-1}$ in 1985 to 617.9 ind. ha^{-1} and 28.6 $m^2\,ha^{-1}$ in 2009. The forest is highly dynamic and has presented fluctuations in stand mortality and recruitment during the study period (Felfili, 1995a,b; Roitman, 2011) (Table 1).

2.2. Sampling

The sample consists of 151 permanent plots of 10 m × 20 m (3.02 ha) contiguously distributed in 10 transects, perpendicular to the water course and 100 m apart (Fig. 1). Data consisted of all stems with girth ≥ 31 cm (≅10 cm diameter) at breast height, measured in 1985, 1988, 1991, 1994, 1999, 2004, and 2009. Matrix models included data on all sampled tree species.

2.3. Model construction and analysis

2.3.1. Size–class interval

When choosing size–class intervals we must regard an essential unrealistic assumption of size–class models: all trees in the same class behave exactly the same. Narrow intervals are more precise but may lead to empty states (classes with no trees) or intermediate absorbing states (classes in which all trees are retained), both of which compromise multi-step projections. The balance between size–class and census intervals defines model resolution. For a given calibration period, greater resolution may be gained with smaller size–class intervals. On the other hand, shorter size–class intervals result in a greater number of parameters of the model. Therefore, there should be a compromise in which classes

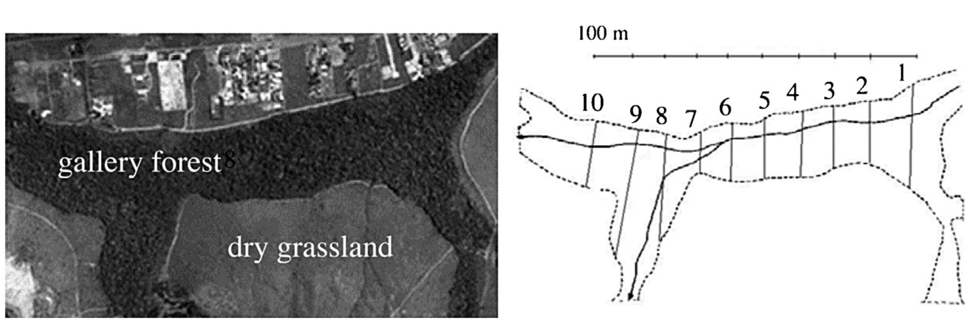

Fig. 1. Gama stream gallery forest in Fazenda Água Limpa, Brasília – DF, and the sample composed of 10 transects perpendicular to the water course.