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Research Article

Thinning Intensity and Pruning Impacts on *Eucalyptus* Plantations in Brazil

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A thinning intensity experiment using the *Eucalyptus grandis* × *E. urophylla* hybrid was conducted at three sites in Bahia State, Brazil. The treatments were a combination of thinning intensities and pruning: 20%, 35%, and 50% basal area removed with no pruning and 35% basal area removed plus pruning (at 27 months). Plots were measured roughly annually from 27 to 165 months. Thinning was implemented on all sites at 58 months and again at 142 months at two of the sites. One of the sites was harvested at 87 months of age. A linear mixed model was applied separately to each installation to test for differences among treatments for mean increment of height, dominant height, quadratic mean diameter, and volume outside bark at the plot level. Additionally, differences in mean monthly increment of basal area and volume outside bark as a percentage of the value at the beginning of the increment period were examined. Increased thinning intensity increased all tree-level variables except dominant height. Pruning had no impact. Observed mortality on all plots was quite low. Thinning intensity response varied among sites and with time since thinning; however, the thinning intensity response was consistent through time among the installations.

1. Introduction

Eucalyptus plantations are important for the Brazilian forest sector. In 2011, the total planted area in Brazil was 6.52 M ha, of which 4.87 M ha was *Eucalyptus*. The area of *Eucalyptus* plantations worldwide in 2009 was approximately 20.1 M ha, with Brazil having the largest area planted (21% of the total), followed by India and China, with 19% and 13% of the total, respectively [1].

Eucalyptus plantations in Brazil primarily have been used for pulp and paper (71.2%), charcoal-based steel industry (18.4%), and industrialized wood panels (6.8%) [2]. These uses have been met to a large extent by short-rotation pulp logs. The demand for sawlogs (requiring trees with high wood density and volume) has been met primarily by harvesting native forests or through imports.

As the production of *Eucalyptus* trees with high individual volumes has not been a priority for companies in Brazil, thinning has not been a common practice. Consequently, there are few *Eucalyptus* thinning intensity studies in Brazil. However, responses of *Eucalyptus* to different thinning intensities have been studied in several other countries. Forrester et al. [3] summarized a number of examples; more recent *Eucalyptus* thinning intensity studies also exist (e.g., [4–7]). In general, the main reason for thinning in *Eucalyptus* is to produce more valuable end products, with fewer but larger stems and lower mortality. Thinned, short-rotation *Eucalyptus* stands can yield at least the same amount of biomass as unthinned stands [8].

Although more Brazil's native forests are being excluded from wood production due to environmental policies and regulations [9], Brazilian participation in the global market for solid wood products could increase as a result of thinning in *Eucalyptus* plantations. This should help reduce pressure on the native forests. Thus, studies of thinning intensity in *Eucalyptus* plantations in Brazil are strategic, both economically and environmentally.

At present, no growth and yield model calibrated to Brazilian conditions is available to predict *Eucalyptus* plantation development under a variety of thinning regimes. Developing a new model or calibrating an existing model will require suitable data. Such data should come from field experiments that respect the principles of experimentation, while creating suitable response surfaces for development of growth and yield models [10, 11].

The objectives of this study are to assess the effects of thinning intensity on selected tree and stand variables in *Eucalyptus* plantations and examine the available data for subsequent use in developing growth and yield models. These analyses are intended as an initial step in developing a growth and yield model suitable for predicting response from thinning intensity in *Eucalyptus* plantations in Brazil.

2. Materials and Methods

2.1. Description of the Study Area and Experimental Design. This study was conducted using an experiment established in September 1995 in planted stands of a *Eucalyptus grandis* × *E. urophylla* hybrid aged 27 months, located in the northeast region of Bahia State, Brazil. The area is owned by Copener Florestal Ltd. The initial spacing between trees was 3 × 3 m.

The experiment was established at three sites (installations): Bonfim (11°52′ S and 38°32′ W, 285 m elevation, and 900 mm average annual precipitation), Tombador (12°03′ S and 38°28′ W, 290 m elevation, and 1100 mm average annual precipitation), and Lagoa do Bu (11°47′ S and 37°55′ W, 150 m elevation, and 1200 mm average annual precipitation). There is no pronounced dry season, although the highest rainfall occurs in April through August. Site quality in this region is primarily influenced by precipitation and was considered to be low, medium, and high, respectively, for these three installations.

The experiment was a randomized block design with replicates on each block. Four treatments were applied: (1) 20% basal area removal without pruning; (2) 35% basal area removal without pruning; (3) 50% basal area removal without pruning; and (4) 35% basal area removal of trees that were pruned to a height of 6 m at 27 months of age. The pruning treatment removed 0.4, 0.1, and 1.5 m of the live crown on average, at the Bonfim, Tombador, and Lagoa do Bu installations, respectively. Thinning was applied at all three installations at 58 months of age and again at 142 months of age at the Bonfim and Tombador installations. Thinning was selective and from below, focused on removing smaller trees and trees with defects. The timing of the thinning was determined from the study by Leite et al. [12]. Each installation received the standard soil preparation and fertilization regime used by Copener Florestal Ltd.; no fertilization occurred after thinning.

Two blocks were installed at each installation and each treatment was replicated twice on each block (eight permanent plots per block). Plots were rectangular and 0.26 ha in size. There were 48 plots in total in the experiment (3 installations × 2 blocks × 2 repetitions × 4 treatments). Plots were buffered from adjacent treatments by a few rows of trees on each side.

The following variables were measured on each plot at 27, 40, 50, 61, 76, 87, 101, 122, 137, 147, 157, and 165 months of age: (i) dbh of all trees (D); (ii) total tree height (H_t) of approximately 15 trees, selected randomly; (iii) total tree height of 5 dominant trees (H_{dom}); and (iv) quality of each tree (forked, dominant, normal, harvested, or dead). Stem analyses were performed on a selection of the felled trees at the time of the first thinning and at the time of final harvest. Both stem analysis datasets covered the range of dbh classes and treatments and were intended to provide data for fitting equations to predict tree volumes. The following variables were recorded on each tree included in the stem analyses: D, H_t, and diameters outside bark (d_i) and the bark thickness at various heights (h_i) from the base (0.1 m, 0.7, 1.3, and 2.0 m and along the stem every subsequent 2.0 m to the tip). The first stem analysis dataset was comprised of 277 trees from across the three installations. The second stem analysis dataset was comprised of 160 trees (40 per treatment) collected only at the Tombador installation.

The Lagoa do Bu installation was harvested after the 87-month measurement; the other two installations were harvested after the 165-month measurement.

2.2. Calculations and Data Analysis. Smalian's formula was used to compute the volume outside and inside bark of each tree section in the stem analysis dataset. Sectional volumes were summed to provide estimates of individual tree volumes. Schumacher and Hall's [13] equation was fit to these data to provide a volume equation. This equation was then used to predict the total volume (V_t), outside and inside bark of each tree in every permanent plot. Total tree heights not measured in the field with a hypsometer were estimated using equations based on age, site index (SI), and dbh. The functions used were

$$\ln(V_t) = \ln(\beta_1) + \beta_2 \times \ln(D) + \beta_3 \times \ln(H_t) + \ln(\varepsilon), \quad (1)$$

$$\begin{aligned} \ln(H_t) = \ln(\varphi_1) &+ \varphi_2 \times \ln(\text{Age}) + \ln(\varphi_3) \times \text{Age} \\ &+ \varphi_4 \times \ln(\text{SI}) + \varphi_5 \times \text{SI} + \varphi_6 \times \ln(D) \\ &+ \ln(\varphi_7) \times D + \ln(\varepsilon), \end{aligned} \quad (2)$$

where ln is the natural logarithm, β_i and φ_i are parameters to be estimated, and ε is the random error term. The other variables are as defined previously.

For each plot and measurement period, the following variables were calculated: basal area per ha (BA ha^{-1}) in m^2; quadratic mean diameter (QMD) in cm; mean total height ($\overline{H}_t$) in m; mean dominant height ($\overline{H}_{\text{dom}}$) in m; SI in m, with an index age of 87 months from planting; number of trees per hectare (trees ha^{-1}); mean tree volume outside bark ($\overline{V}_{\text{tob}}$ tree^{-1}) and inside bark ($\overline{V}_{\text{tib}}$ tree^{-1}) in m^3; and volume per

Table 1: Estimates of parameters and adjusted coefficients of determination ($\overline{R}^2$) for the volume equations, outside and inside bark, and the height prediction (hypsometric) equations for each installation. All terms were significant at $\alpha = 0.01$.

	Hypsometric model			Volume model	
	Bonfim	Tombador	Lagoa do Bu	Outside bark	Inside bark
$\ln(\beta_1)$				−10.2886	−10.3916
β_2				1.7512	1.7425
β_3				1.2352	1.2237
$\ln(\varphi_1)$	−29.3274	38.2381	−32.4050		
φ_2	0.4228	0.4593	0.8582		
$\ln(\varphi_3)$	−0.0023	−0.0024	−0.0077		
φ_4	12.9284	−17.2182	12.6711		
$\ln(\varphi_5)$	−0.4936	0.6872	−0.4116		
φ_6	0.6417	0.5441	0.8171		
$\ln(\varphi_7)$	−0.0168	−0.0123	−0.0301		
$\overline{R}^2$	0.97	0.97	0.98	0.98	0.98

hectare outside bark (V_{tob} ha^{-1}) and inside bark (V_{tib} ha^{-1}) in m^3.

The statistical analysis consisted of testing differences among thinning intensity treatments for the following: (1) monthly increment of mean total height (PIH_t), dominant height (PIH_{dom}), quadratic mean diameter (PIQMD), and volume per tree outside bark (PIV_{tob} tree^{-1}) and (2) monthly increment of basal area per hectare (%PIBA) and volume per hectare outside bark (%PIV_{tob} ha^{-1}) as a percentage of the value at the beginning of the increment period. Periodic increment was calculated as the difference between the variables for live trees at the start and end of each growth period. The increments periods considered were Period 1, 61 to 87 months (Bonfim and Tombador installations) and 61 to 76 months (Lagoa do Bu installation); Period 2, 87 to 137 months (Bonfim and Tombador installations) and 76 to 87 months (Lagoa do Bu installation); and Period 3, 147 to 165 months (following the second thinning, Bonfim and Tombador installations).

The design was a replicated, randomized complete block with repeated measures. A linear mixed model was used for the analysis, where period was treated as a split plot, fitted to each individual installation using SAS Proc Mixed, version 9.2 [14]. Block, block × thinning, repetition (block × thinning), period, and period × thinning were considered random effects, and thinning intensity was considered a fixed effect. Pairwise comparisons were made using the Bonferroni test. The univariate procedure of SAS was used to test for normality and graphs of residuals versus predicted values were used to assess the homogeneity of variance. All statistical tests were conducted with $\alpha = 0.05$.

A graphical procedure, as proposed by Vanclay et al. [11], was used to examine the existing database for suitability for growth and yield modelling. According to these authors, critical evaluation of a database requires careful choice of the axes used in the graphs. The variables used should be (1) fundamental to the stand dynamics and growth model, (2) able to be measured directly, and (3) those with minimal measurement error. In this study, we used stems per ha versus quadratic mean diameter to assess the range of stand conditions present in the data set.

3. Results and Discussion

3.1. Estimates of Tree Volume and Height. The adjusted coefficients of determination for the equations for estimating individual tree volumes and heights of trees not measured by hypsometer were all greater than 0.97; parameter estimates were logical and coefficients were significant (Table 1). These equations provided accurate estimates and there were no obvious trends in the residuals (Figure 1).

Total height growth varied over time, likely due to variability in precipitation; however, (2) was flexible enough to capture this variation. Changes in the sign of the intercept ($\ln(\varphi_1)$) and of coefficients related to the site index (φ_4 and $\ln(\varphi_5)$) indicate that this equation also was sufficiently flexible to express the productivity differences across the three installations.

3.2. Response to Thinning Intensity. Plotting average values for several variables over time by treatment clearly showed that growth rates were affected by thinning intensity and that pruning had no effect on stand development (i.e., the 35% thinning with pruning mirrored the results for the 35% thinning with no pruning) (Figure 2). This result for pruning implies that the trees were able to recover the leaf area removed quickly and agrees with other studies where pruning did not significantly influence the growth of trees in stands of *Eucalyptus* when the pruning lift was relatively moderate (e.g., [15, 16]). This is of interest economically because pruning promotes the production of better quality wood and pruning in conjunction with thinning can substantially increase the volume of clear wood produced in *Eucalyptus* [17].

It was necessary to logarithmically transform %PIV_{tob} ha^{-1} in the Tombador installation and %PIBA and PIQMD in the Lagoa do Bu installation to meet normality assumptions for the mixed linear models. The test of fixed effects using generalized least squares was powerful;

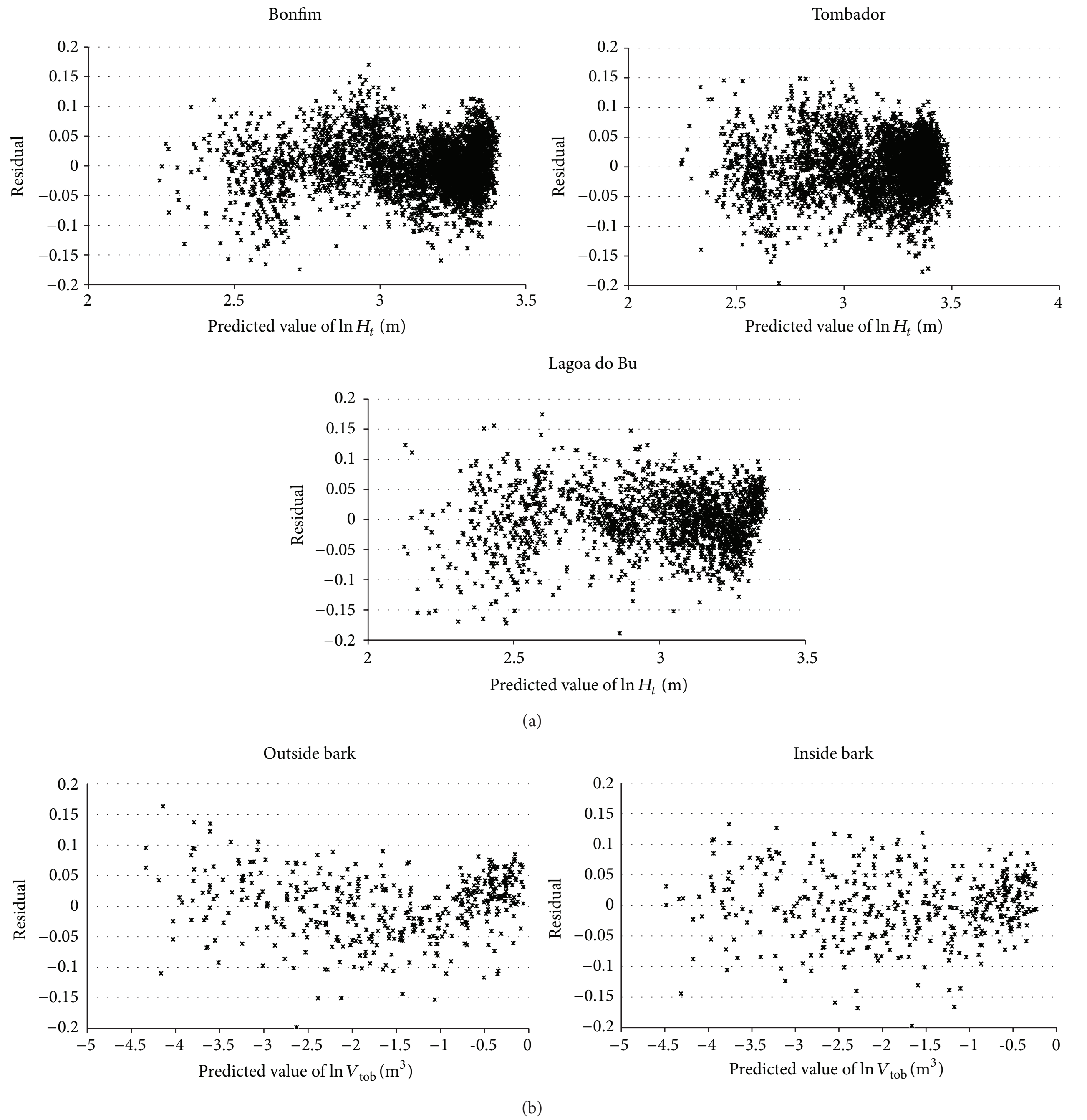

Figure 1: Residual versus predicted values for (a) the height prediction equations and (b) the outside and inside bark volume equations. The predicted and residual values are in natural logarithmic units of m for height (a) and m^3 for volume (b).

significant differences among treatments were found for most of the variables analyzed (Table 2). The power of the test was not surprising since mixed models are useful for analysis of repeated data because the methodology has the ability to handle missing data and unequal time steps and allows the use of covariates to reduce the variation in the response variable [18].

The thinning intensity by period interaction (a random effect) was not significant for any variable or installation. This indicated that the effect of thinning intensity was consistent across the periods considered. For the Bonfim and Tombador installations, thinning intensity (fixed effect) had a significant impact on PIH_t, PIQMD, %PIBA, ln %PIV_{tob}/ha, and PIV_{tob}/tree but not on PIH_{dom}. For the Lagoa do Bu installation, thinning intensity had a significant effect on PIH_t, %PIV_{tob}/ha, and PIV_{tob}/tree but not on PIQMD, ln %PIBA, and PIH_{dom}.

Based on the multiple comparison tests, only thinning 35% and thinning 35% with pruning treatments were not significantly different in PIH_t at Bonfim. At Tombador only

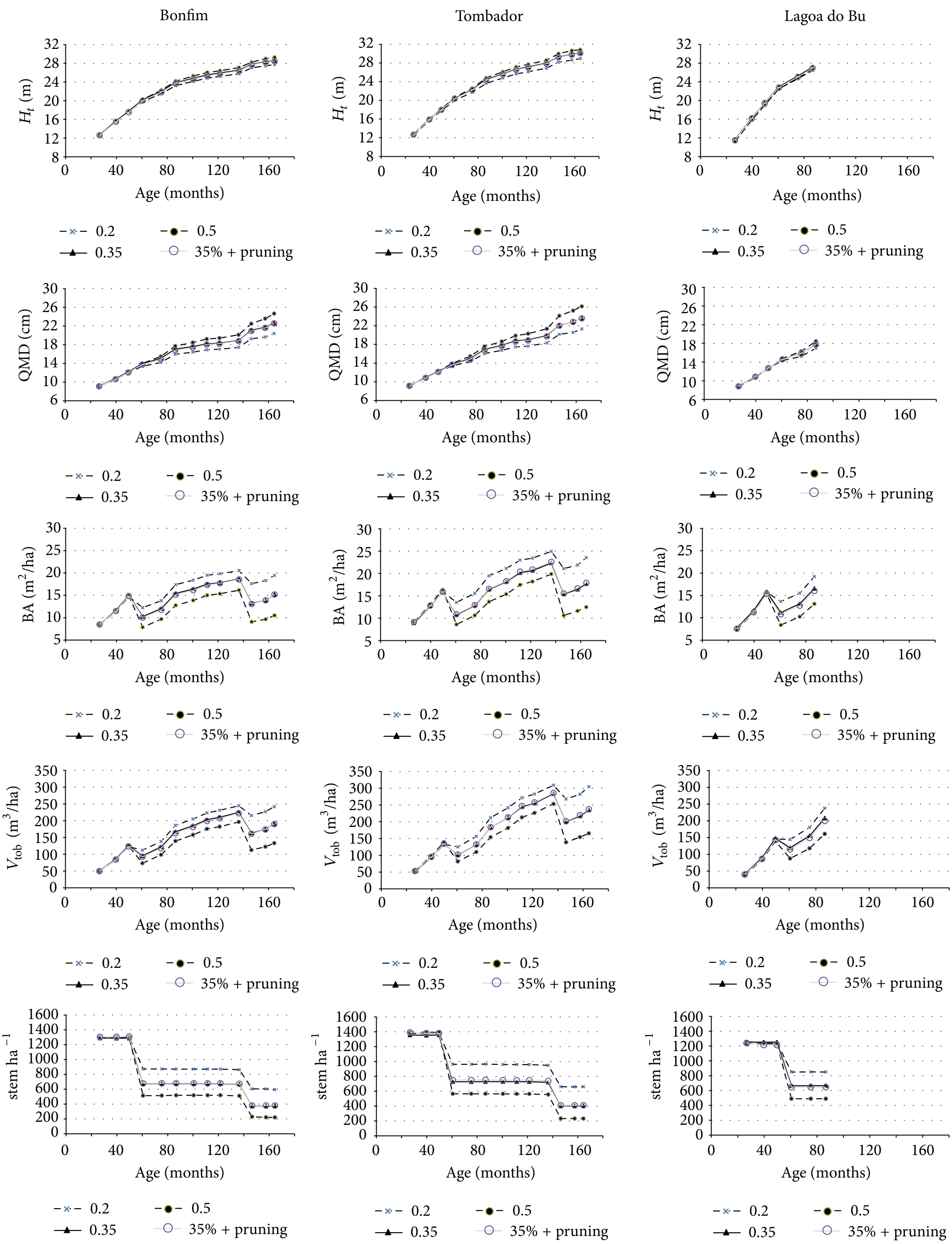

FIGURE 2: Average height (H_t), quadratic mean diameter (QMD), basal area per hectare (BA ha^{-1}), volume per hectare outside bark (V_{tob} ha^{-1}), and stems per hectare (stems ha^{-1}) by installation, treatment, and stand age.

Table 2: Treatment significance (fixed effect) and pairwise comparisons among significant treatments for periodic increment in total height (PIH_t); dominant height (PIH_{dom}); quadratic mean diameter (PIDMQ); basal area (PIBA); volume per hectare outside bark (PIV_{tob} ha^{-1}); and volume per tree outside bark (PIV_{tob} tree^{-1}). P values < 0.05 are bolded.

Installation	Variable	P value for thinning	Pairwise comparisons	P value
Bonfim	PIH_t	<**0.0001**	20% versus 35%	**0.0077**
			20% versus 50%	<**0.0001**
			20% versus 35% + pruning	**0.0038**
			35% versus 50%	**0.0001**
			35% versus 35% + pruning	0.7914
			50% versus 35% + pruning	**0.0002**
	PIH_{dom}	0.6087		
	PIQMD	<**0.0001**	20% versus 35%	**0.0002**
			20% versus 50%	<**0.0001**
			20% versus 35% + pruning	**0.0001**
			35% versus 50%	**0.0001**
			35% versus 35% + pruning	0.5154
			50% versus 35% + pruning	<**0.0001**
	PIV_{tob} tree^{-1}	<**0.0001**	20% versus 35%	**0.0027**
			20% versus 50%	<**0.0001**
			20% versus 35% + pruning	**0.0033**
			35% versus 50%	**0.0007**
			35% versus 35% + pruning	0.8961
			50% versus 35% + pruning	**0.0006**
Tombador	PIH_t	**0.0313**	20% versus 35%	**0.0290**
			20% versus 50%	**0.0065**
			20% versus 35% + pruning	**0.0316**
			35% versus 50%	0.2668
			35% versus 35% + pruning	0.9502
			50% versus 35% + pruning	0.2448
	PIH_{dom}	0.7942		
	PIQMD	**0.0005**	20% versus 35%	**0.0033**
			20% versus 50%	<**0.0001**
			20% versus 35% + pruning	**0.0031**
			35% versus 50%	**0.0025**
			35% versus 35% + pruning	0.9502
			50% versus 35% + pruning	**0.0027**
	%PIBA ha^{-1}	**0.0046**	20% versus 35%	**0.0162**
			20% versus 50%	**0.0007**
			20% versus 35% + pruning	**0.0152**
			35% versus 50%	**0.0233**
			35% versus 35% + pruning	0.9620
			50% versus 35% + pruning	**0.0249**
	ln%PIV_{tob} ha^{-1}	<**0.0001**	20% versus 35%	<**0.0001**
			20% versus 50%	<**0.0001**
			20% versus 35% + pruning	<**0.0001**
			35% versus 50%	**0.0017**
			35% versus 35% + pruning	0.7895
			50% versus 35% + pruning	**0.0035**
	PIV_{tob} tree^{-1}	**0.0010**	20% versus 35%	**0.0057**
			20% versus 50%	**0.0001**
			20% versus 35% + pruning	**0.0065**
			35% versus 50%	**0.0051**
			35% versus 35% + pruning	0.9075
			50% versus 35% + pruning	**0.0045**

Table 2: Continued.

Installation	Variable	P value for thinning	Pairwise comparisons	P value
Lagoa do Bu	$\mathrm{PI}H_t$	**0.0402**	20% versus 35%	**0.0208**
			20% versus 50%	**0.0097**
			20% versus 35% + pruning	0.0618
			35% versus 50%	0.5904
			35% versus 35% + pruning	0.4727
			50% versus 35% + pruning	0.2279
	$\mathrm{PI}H_{\mathrm{dom}}$	0.9899		
	lnPIQMD	0.1257		
	ln%PIB ha^{-1}	0.0682		
	$\%\mathrm{PIV}_{\mathrm{tob}}\ \mathrm{ha}^{-1}$	**0.0263**	20% versus 35%	0.0626
			20% versus 50%	**0.0044**
			20% versus 35% + pruning	0.1279
			35% versus 50%	0.0963
			35% versus 35% + pruning	0.6416
			50% versus 35% + pruning	**0.0471**
	$\mathrm{PIV}_{\mathrm{tob}}\ \mathrm{tree}^{-1}$	**0.0322**	20% versus 35%	**0.0311**
			20% versus 50%	**0.0097**
			20% versus 35% + pruning	**0.0365**
			35% versus 50%	0.0798
			35% versus 35% + pruning	0.7880
			50% versus 35% + pruning	0.0650

thinning 20% differed from the other treatments in terms of $\mathrm{PI}H_t$, and at Lagoa do Bu, thinning 20% differed from thinning 35% and thinning 50% in terms of $\mathrm{PI}H_t$. For PIQMD, %PIBA, and $\mathrm{PIV}_{\mathrm{tob}}$/tree at Bonfim and Tombador and $\ln \%\mathrm{PIV}_{\mathrm{tob}}$/ha at Tombador, only thinning 35% and thinning 35% with pruning were not significantly different. At Lagoa do Bu, only thinning 20% differed from the other treatments for $\mathrm{PIV}_{\mathrm{tob}}$/tree; for $\%\mathrm{PIV}_{\mathrm{tob}}$/ha, thinning 20% differed from thinning 50%, and thinning 50% differed from 35% thinning with pruning.

For the Bonfim installation, %PIBA and $\%\mathrm{PIV}_{\mathrm{tob}}$/ha did not meet the normality assumptions in either original or logarithmically transformed units. Therefore, graphs of %PIBA and $\%\mathrm{PIV}_{\mathrm{tob}}$/ha over the periods (Figure 3) were used to examine thinning intensity effects. Thinning 35% and thinning 35% with pruning appeared to be equal and response to thinning 20% appeared different from thinning 50%.

More intensive thinning led to larger dbh and slightly taller trees on average; consequently, the residual trees had higher volumes. However, the higher volume of the residual trees was coupled with lower basal area and volume per hectare. Thinning in the manner conducted in this study (i.e., from below targeting poorer trees) greatly reduced the mortality below that expected for denser plantations of *Eucalyptus*; mortality was minimal for all treatments at the three installations. The decrease in the numbers of trees in the treated plots over time essentially reflected the trees removed during the first and second thinning.

Dominant height was not affected by thinning intensity, confirming that it is little affected by variation in stand density and is therefore useful as a basis for site quality estimation in thinned *Eucalyptus* stands. However, the mean total height was affected by thinning intensity. This result is related to the increasing removal of smaller (shorter) trees with increasing thinning intensity, rather than a response of the residual trees to thinning intensity. The thinning treatments were selective and from below, focusing on removing smaller trees and trees with defects. Site quality also appeared to influence the effect of thinning intensity on the change in mean height. At the medium (Tombador) and high site (Lagoa do Bu) installations, only the lightest thinning (20% removal) was significantly lower than the other treatments, while at the low site (Bonfim) installation, mean total height increased significantly with increasing thinning intensity for all three levels.

Quadratic mean diameter was greatly affected by thinning intensity. Thinning from below resulted in an immediate increase in the quadratic mean diameter, with the impact increasing with thinning intensity (i.e., the so-called chainsaw effect). Differences among the thinning intensities increased over time and continued to increase after the second thinning (Figure 2). Basal area per ha growth reflected the changes in quadratic mean diameter growth. However, the differences among thinning intensities for these variables were not statistically significant 29 months after the first thinning.

Volume per hectare growth and volume per tree growth reflected the changes in quadratic mean diameter and average height; consequently, site quality and time since thinning intensity influenced these variables. Thinning on better sites was more likely to produce stronger responses for any intensity of thinning and differences among thinning intensities increased through time.

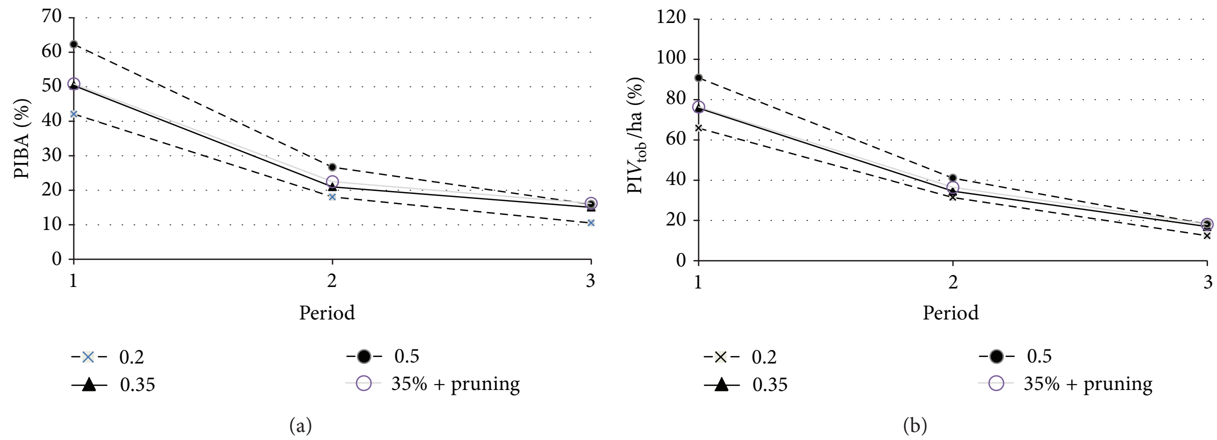

FIGURE 3: Percentage basal area growth (%PIBA) and percentage volume per hectare outside bark growth (%V_{tob} ha^{-1}) over the three periods studied for the Bonfim installation.

As noted previously, the trees at the Bonfim and Tombador installations were harvested after the 165-month measurement; however, the trees were harvested after the 87-month measurement at the Lagoa do Bu installation. Consequently, it was not possible to compare the effect of a second thinning between the highest site quality installation and the other two installations. Another factor that limited the analysis was the absence of a nonthinned control treatment.

Commercial plantations of *Eucalyptus grandis* × *E. urophylla* hybrid with a spacing of 3 m × 3 m owned by Copener Florestal Ltd. are managed for pulp production with a rotation age of 5 years. Average expected attributes at harvest (company data) are the following: 12.4 cm quadratic mean dbh; 19.9 m mean height; 0.117 m^3 mean tree volume outside bark; 15.8 m^2/ha basal area; and 151.9 m^3/ha volume outside bark. Not surprisingly, our thinned plantations (Figure 2) showed higher quadratic mean dbh values, higher mean tree volumes, similar mean tree heights, lower basal area per ha, and lower volume per ha at 60 months.

The thinning intensity responses seen in this study were consistent with results from several published studies, especially those based on specific designs for studying density and growth, such as correlated curve trend experiments [19] and levels-of-growing-stock installations [20]. There was agreement in terms of major effects with the results of *Eucalyptus* thinning intensity in South Africa [21], in New Zealand [22], in Australia [23], in Brazil [24], and in China [25]. However, because growing conditions and experimental designs differed, there were differences in the magnitude of the responses between this study and the other *Eucalyptus* studies cited above.

3.3. Appropriateness of the Database for Growth and Yield Model Development. The database used in this study was consistent with recommendations by Vanclay [10], Curtis and Marshall [26], and others for providing a good foundation for growth and yield model development. In general, sampling for developing growth and yield models should meet the following requirements: (1) the frequency of the data (sample size and number of measurements) is adequate for regression analysis; (2) sampling intensity is directly proportional to the heterogeneity of the characteristic to be evaluated; (3) sample units are permanent; (4) the sample units are sufficiently large to faithfully represent the silvicultural practices applied to the remainder of the stand; and (5) selection of the sample units was deliberate (selective sampling) so that it represents well the range of conditions present.

The graph of stocking (stems/ha) versus quadratic mean diameter (Figure 4) illustrates that a wide range of sites have been sampled and that some plots represent extremes of stand density since the data are clustered in a wide belt. There is a range of stocking present at any stage of development, indicating that these data provide a sound basis for making inferences about silvicultural alternatives. Consequently, the database appears suitable as a starting point for developing growth and yield models for thinned *Eucalyptus* stands in Bahia State.

4. Conclusions

Increasing thinning intensity reduced mortality and increased individual tree dbh, height, and volume but did not affect the dominant stand height. Higher intensity thinning resulted in lower basal area and volume per ha. The pruning that took place had no impact on *Eucalyptus* growth. Response to greater thinning intensity varied among sites and with time since thinning; however, the thinning intensity response by treatment was consistent through time among the installations. We believe that the dataset used in this study provides a sufficient basis for development of a growth model that incorporates the effect of thinning intensity on *Eucalyptus* growth and development in Bahia State, Brazil.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

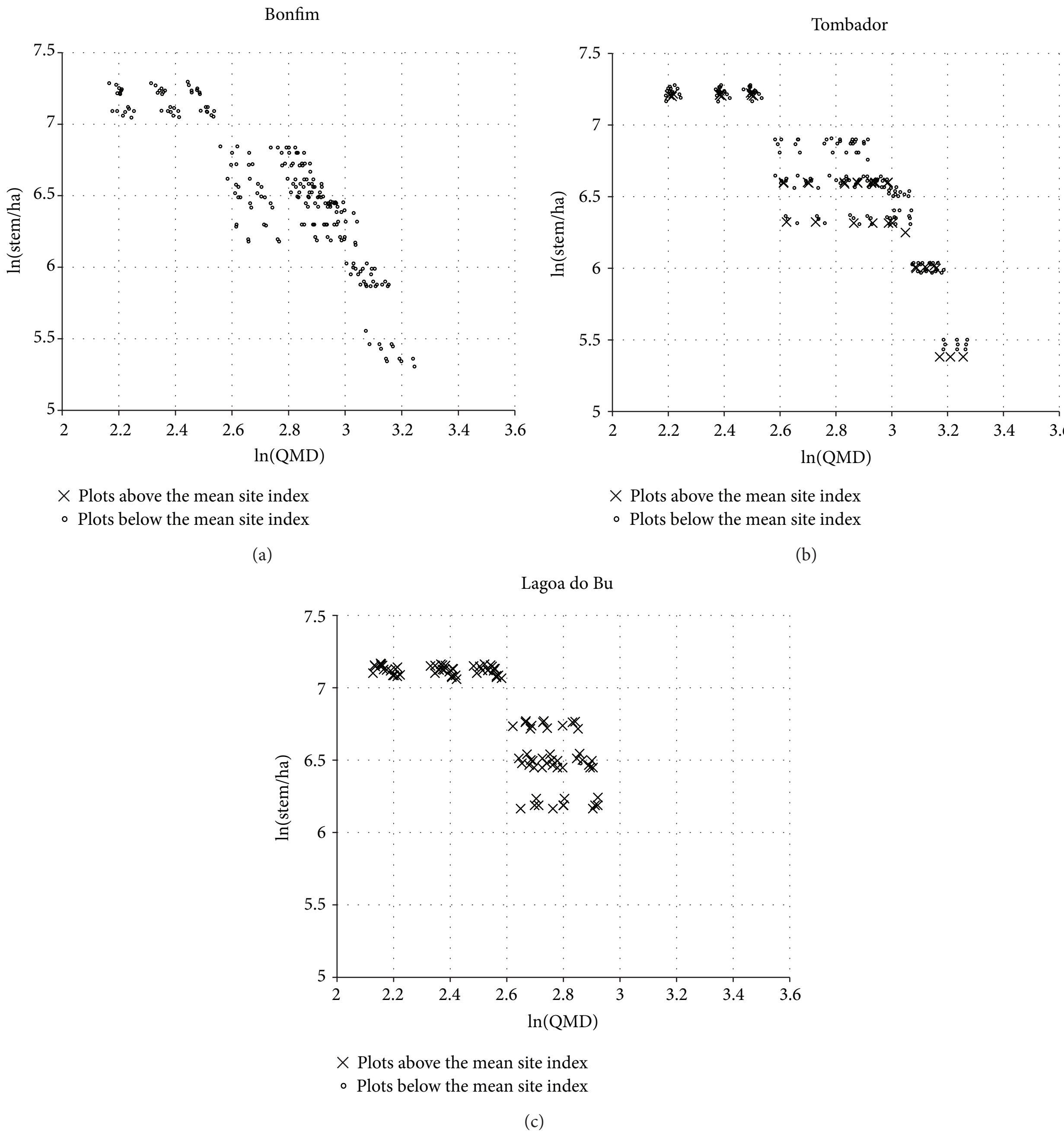

Figure 4: Mean tree size (lnQMD) and stand density (In(stems ha^{-1})) at the Bonfim, Tombador, and Lagoa do Bu installations.

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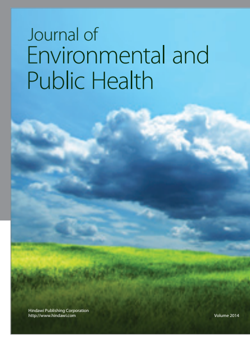
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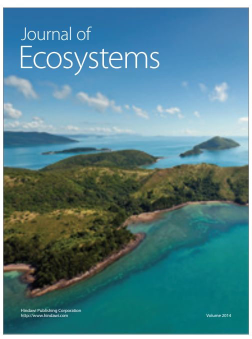
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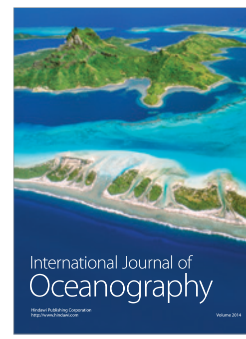
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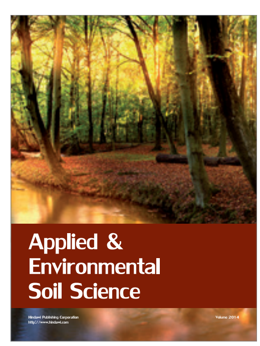
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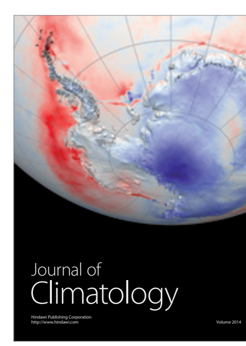
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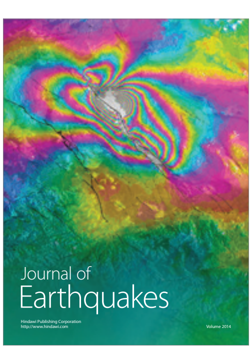
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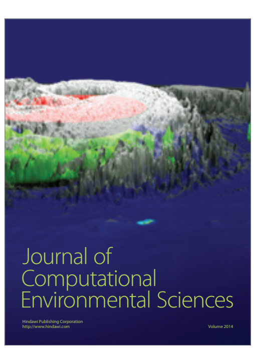
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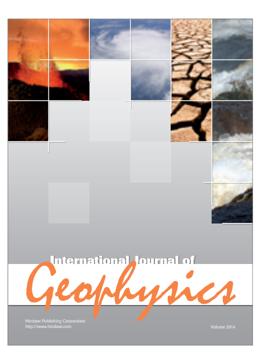
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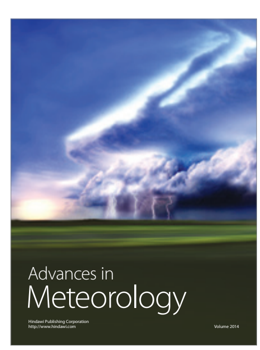
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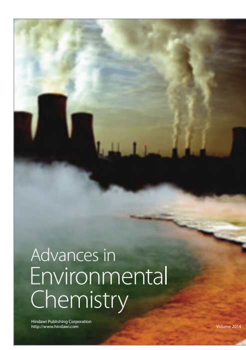
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