Land Use Policy 58 (2016) 133–144

Contents lists available at ScienceDirect

Land Use Policy

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

Drivers of land change: Human-environment interactions and the Atlantic forest transition in the Paraíba Valley, Brazil

Ramon F.B. da Silva[a,*], Mateus Batistella[b], Emilio F. Moran[c]

[a] Center for Environmental Studies and Research, University of Campinas, Campinas, SP 13083-867, Brazil
[b] EMBRAPA, Brazilian Agricultural Research Corporation, Brasília, DF 70770-901, Brazil
[c] Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI 48823, USA

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 7 July 2016
Accepted 19 July 2016

Keywords:
Land use change models
Multi-layer perception neural network
Forest transition
Tropical forest

ABSTRACT

Human societies constantly interact with the environment through mutual feedbacks and adaptations. The aim of this research was to analyze human and environmental dimensions so as to understand how the dynamic processes of land use and land cover change are contributing to the increase of forest cover observed between 1985 and 2011 in the Paraíba Valley, Brazil. The forestry sector, based on eucalyptus plantations, is given particular attention due to its role in these change processes. Multi-layer perception neural network (MPNN) models were adopted to evaluate the influence of independent variables in the process of the forest transition. Based on the model's results, we conclude that the process is conditioned by a set of biophysical and socioeconomic variables that operate during different historical periods and in different landscape settings. The proximity of Atlantic forest remnants was influential in the forest transition for the three periods analyzed: 1985–1995, 1995–2005, and 2005–2011. In the first period of change (1985–1995), topography was most influential. Between the periods of 1995–2005 and 2005–2011, the proximity to eucalyptus plantations was an important factor, indicating a high probability of native forest recovery occurring in the vicinity of these monocultural areas. The forest transition tends to occur in areas less suitable for agriculture at the outset, but as these areas are replaced by forest cover, socioeconomic drivers such as farm credit and economic development play important roles in forest recovery.

1. Introduction

Land use and land cover changes (LULCC) are key factors in environmental changes operating at global and regional scales, with impacts on biodiversity, ecosystems services, and climate regulation. There is great space and time variability in the biophysical environments, socioeconomic activities and cultural contexts associated with LULCC (Lambin et al., 2003).

The land change process governed by the increase of forest cover areas over regions previously deforested with the forest net gains surpassing new deforestation rates is known as the forest transition (FT) (Rudel et al., 2005; Rudel et al., 2010), and is a core phenomenon to examine aforestation dynamics. FT pathways (e.g., industrialization, global trade, land ownership regime, land scarcity and agricultural intensification) are not independent and in any particular country or region one can see the overlapping influence of several pathways (Lambin and Meyfroidt, 2010). FT, a phenomenon first observed in European countries and in North America, has roots in the process of industrialization and consequent socioeconomic transformations of rural areas (Foster et al., 1998; Mather et al., 1999; Evans et al., 2005). It has been observed more recently in tropical countries as well (Hecht et al., 2006; Baptista, 2008; Sánchez-Cuervo et al., 2012).

In Europe, research has shown that the effects of political, economic and cultural changes experienced since World War II in natural and cultural landscapes has had consequences to forest cover dynamics (Bieling et al., 2013; Beilin et al., 2014). In many parts of Eastern Europe, changes in forest cover were observed after the collapse of the Soviet Union, with transition periods marked by deforestation followed by gradual increases in forest cover in the following decades (Baumann et al., 2012; Griffiths et al., 2012).

In Colombia, land abandonment, an important land change process that fosters FT (Rudel et al., 2005; Meyfroidt et al., 2010; Prishchepov et al., 2012; Beilin et al., 2014; Queiroz et al., 2014), in the past few decades has been partly motivated by the armed conflict and the erradication of coca plantations that has led some regions to have significant rates of native vegetation recovery

---

* Corresponding author.
E-mail addresses: ramonbicudo@gmail.com (R.F.B.d. Silva), mateus.batistella@embrapa.br (M. Batistella), moranef@msu.edu (E.F. Moran).

http://dx.doi.org/10.1016/j.landusepol.2016.07.021

(Sánchez-Cuervo et al., 2012). In Vietnam, the agricultural intensification of smallholders in lowlands of marginal regions associated with forestland allocation and zoning policies contributed significantly to the increase of forest cover in mountainous regions (Lambin and Meyfroidt, 2010). Southern Mexico has experienced FT as a result of passive processes related with reductions in land use intensity (Vaca et al., 2012).

In Brazil, the national rates of forest loss still outweigh gains in recovery (FAO, 2011), however, the reverse has been observed in some specific regions (Baptista, 2008; Farinaci, 2012; Silva, 2015). Perz and Skole (2003) demonstrated that biophysical constraints and capital scarcity in the Brazilian Amazon limited land settlement and a shift from crops to pasture, resulted in regional forest transitions, suggesting in the case of the Amazon, a series of small and short-term FT episodes. The forestry sector (based on *Eucalyptus spp* plantations) has raised some questions about its positive effects on FT in Atlantic Forest regions because of the sector's commitment to environmental policies and international certification protocols (Farinaci et al., 2013). Through management plans for harvesting, forest restoration projects inside forestry company's private areas, connectivity and conservation of native forest remnants close to eucalyptus plantations, the forestry sector may favor FT process at regional scale.

This paper conducted a spatio-temporal analysis of land use and land cover changes in a portion of the Atlantic Forest in southeastern Brazil between 1985 and 2011. Focused on the remarkable case of regional FT in Paraíba Valley (Silva et al., 2016), this study aims to *(i)* identify the most influential variables (drivers) acting on the FT process taking place in the region, and *(ii)* understand how the dynamic of eucalyptus plantations may be related to forest cover change and influence the FT.

2. Brazil, Atlantic forest and the Paraíba Valley: temporal and spatial scales

The replacement of natural ecosystems by production systems, based on monoculture cropping and/or livestock expansion, was primarily responsible for the deforestation of the Atlantic Forest biome (Teixeira et al., 2009; Rodrigues and Gandolfi, 2007). Currently, forest remnants of this biome comprise around 13% of the original vegetation cover (Ribeiro et al., 2009), and the Atlantic Forest is the Brazilian biome with the highest number of extinct and endangered species. Among the list of species of flora and fauna endangered or extinct, 58% and 63% belong to the Atlantic Forest, respectively (MMA, 2008; Machado et al., 2008).

In 1962, the native forest vegetation, consisting of secondary successional forests and mature forests, comprised 13% of the State of São Paulo and 16% of the Paraíba Valley's land cover (Borgonovi et al., 1967). The same study reveals that the Paraíba Valley region was covered by 1% of planted forests (monoculture plantations of *Pinus elliottii* and *Eucalyptus spp*).

Between 1950 and 1980, Brazil experienced an intense process of urbanization and industrialization, a result of import substitution economic policies (Target Plan/*Plano de Metas* in Portuguese), producing changes in the economy, politics and society (Brito, 2006; Alves et al., 2011). In 1950, 64% of the population lived in rural areas (IBGE, 1950). During the Brazilian military regime (1964–1985) modernization of large-scale and export-oriented agriculture was stimulated (Freitas, 2008). The process of industrialization and socioeconomic changes during this period of Brazilian history resulted in a rural exodus to cities, which led the country to a new agricultural economic configuration, and new standards of rural and urban ways of life (Alves et al., 2011).

Between 1959 and 1985, the economic contribution of the Paraíba Valley to the Gross Domestic Product (GDP) of São Paulo State increased from 1.97% to 7.43% (Vieira, 2009). The region's economic development was the result of industrial policies, the construction of the President Dutra highway, as well as public and international investments. As a result, intense migration fluxes from poorer rural municipalities to urban-industrial ones took place (Vieira and Santos, 2012). The replacement of agricultural activities by pastures in the 1970s also reduced employment in the rural areas of the Paraíba Valley (Vieira, 2009).

In the 1980s, the Paraíba Valley consolidated its industrial development (Boffi et al., 2006), and its rural population decreased from 55% in 1950 to 5.8% by 2010. Until the 1980s, the protection of the Atlantic Forest biome was restricted by the Brazilian Forestry Code, dating back to 1965. The Brazilian Federal Constitution of 1988 recognized the biome as a national heritage area (art. 225), and in 1990 a Federal Decree (bill 99547) prohibited the harvest and use of natural vegetation for any purpose (Lima and Capobianco, 1997). In 1993, a new policy was approved by the National Environmental Council (CONAMA), which extended the biome protection to the secondary succession formations in the early, middle and advanced stages of regeneration further supporting the restoration of forests.

In 2006 the Atlantic Forest biome became protected by the Federal Law n^0 11428, which regulates the practices of deforestation and condemns transgressions as environmental crimes, according to the Federal Law n^0 9605 of 1998 (Federal Law of Environmental Crimes).

During recent decades, forestry activities in the Paraíba Valley, based on eucalyptus plantations, developed economically and technologically (Itani et al., 2011), and promoted impacts on land use, environment and society (Farinaci, 2012; Silva et al., 2016; Farinaci et al., 2013). This economic sector has its foundations in 1958, when the region hosted its first pulp and paper industry in the city of Jacareí. At the time of the military regime, the "National Plan for Pulp and Paper (1974)" promoted the increase of areas occupied by planted forests and aimed to make Brazil a self-sufficient country and eventually to become an exporter of eucalyptus fiber (Queiroz and Barrichelo, 2008). The expansion of eucalyptus cultivated areas (Silvestre and Rodriguez, 2007) created tensions between social actors that have benefited from this policy (steel and forestry companies) and those excluded, namely, traditional farming families (Calixto and Ribeiro, 2007).

Currently, eucalyptus in the Paraíba Valley is a commodity dedicated to the production of cellulose pulp traded in international markets. In 2011, 89% of the cellulose pulp production was exported, mainly to Europe and China (Brandão, 2011). The broad scope of the Brazilian environmental policies to protect the Atlantic Forest biome, as well as the commitment of the Valley's forestry sector to maintain forest certifications to trade cellulose pulp in international markets, are overlapping its influence alongside eucalyptus plantations inside companies' private areas. According to Lambin and Meyfroidt (2010), the FT may be induced through the *global diffusion of environmental conservation ideas* pathway. The eucalyptus' influence to the FT will be examined in the results and discussion sections of this paper.

3. Study area

The Paraíba Valley (14,000 sq.km, Fig. 1) was one of the first areas occupied in Brazil (Dean, 1996). Far from being of great importance to the colonial economy, it was not until the first half of the 19th century that coffee plantations made their way there. After that, the region became a part of this important export crop and a contributor to the national economy (Zuquim, 2007; Ricci, 2008; Couto and Serra, 2011). Coffee plantations were responsible for the first deforestation cycle in the Paraíba Valley, declining only with the end of slavery. New coffee productive areas in the Central-West

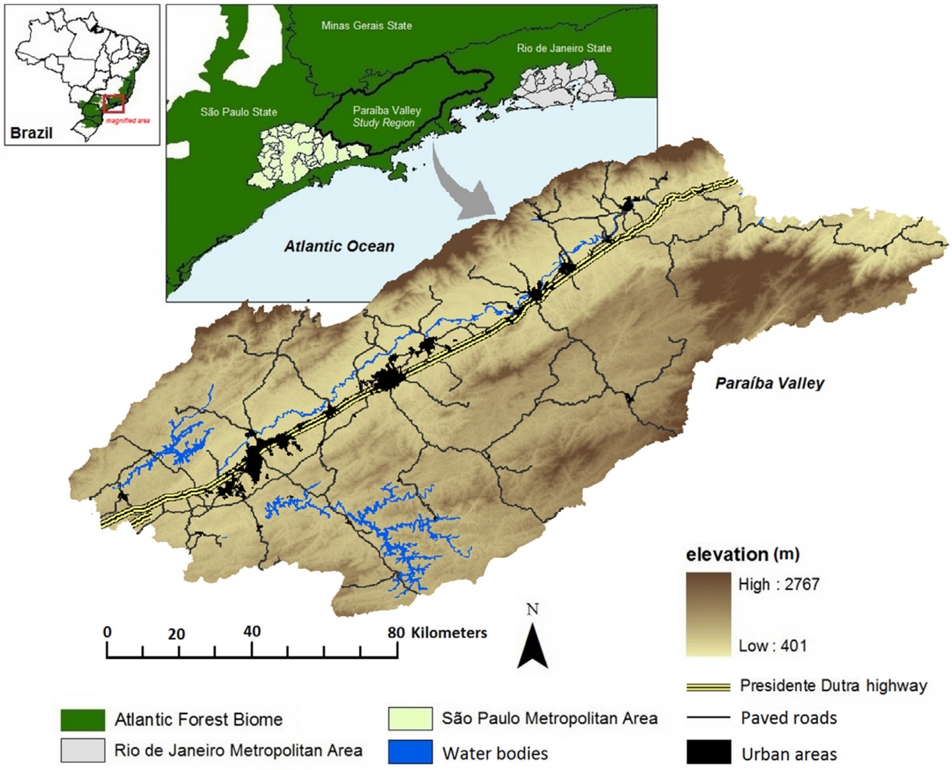

Fig. 1. Study area: Paraíba Valley, located between the São Paulo and Rio de Janeiro metropolitan areas.

region of São Paulo State that developed after the expansion of railways system and land degradation in the Paraiba Valley, resulted in the decline of coffee in the Valley (Drummond, 1997; Zuquim, 2007). During the 20th century, cattle ranching replaced coffee as a major form of land use and maintained the pressure on forest remnants. In the 1980s, while soil and pasture degradation dominated the hilly landscapes (Ferreira et al., 2006; Vieira and Santos, 2012), new economic shifts in Brazil, namely industrialization, resulted in land abandonment (Vieira, 2009; Itani et al., 2011).

Today, landscapes are dominated by pastures in different stages of degradation, forest remnants, eucalyptus plantations, secondary succession, and urban areas concentrated along the President Dutra highway. Cultural, rural, and ecological tourism linked to the historical past and environmental attractions have increased as a rural economic activity in the last decade (Couto and Serra, 2011). Composed by 34 municipalities and accounting for 4.5% of São Paulo state's GDP, the Paraíba Valley lies in the connection axis between two major metropolitan areas of Brazil, i.e. São Paulo and Rio de Janeiro. Due to its steep and mountainous topography, the region is considered by the Consortium for Integrated Development of Paraíba Valley as unfavorable for the development of large-scale mechanized agriculture. A poorly developed rural road network further contributes to this scenario. The eucalyptus plantations developed in recent decades have spread over diverse topography gradients in the region but in recent years, the forestry management operations have taken place, predominantly, in areas with slopes up to 46%, a threshold for forestry mechanization (North et al., 2015). Topography is a limiting factor in the mechanical harvesting process; and the operation costs increase the greater the slope. This is a limiting factor to the expansion of forestry activities in the Paraíba Valley while new producer areas are developing, e.g. in Mato Grosso State (Silva, 2015).

4. Methods

The research draws on satellite-based land use and land cover data matched to a geographic information system (GIS) and census-based social and agricultural data for Brazilian municipalities between 1985 and 2011, and to biophysical features of the landscape (e.g., elevation). To analyze the influence of independent variables (census data and biophysical features) on the FT process in the Paraíba Valley, a Multi-layer Perception by Neural Network (MLPNN) model was applied for three distinct time periods, 1985–1995, 1995–2005, and 2005–2011.

4.1. Land use and land cover data

The land use and land cover data are derived from previous research conducted in the Paraíba Valley (Silva et al., 2016). A set of Landsat-5 Thematic Mapper (TM) scenes (218/76 and 219/76) was selected because of reliable temporal coverage and spatial resolution in the study region, from 1985 until 2011. The thematic maps were developed to the years of 1985, 1995, 2005 and 2011. Land use and land cover change (LULCC) analyses were carried out for the time periods 1985–1995, 1995–2005, and 2005–2011. Image pre-processing included registration and atmospheric correction using the Improved Dark-Object Subtraction (DOS2) method (Chavez, 1988). Based on the review for existing pixel-based classification algorithms (Lu and Weng, 2007), a Maximum Likelihood algorithm (ML) was performed to classify land use and land cover. The thematic mapping reached global accuracy of 85% for 1985, 85% for 1995, 88% for 2005 and 86% for 2011 following accuracy assessment methods proposed by Pontius and Millones (2011). Mapped classes were defined based on the main land uses described by the Watershed Plan of Management of the Paraíba Valley region (Itani et al., 2011) and included: agriculture, water, built-up areas, eucalyptus, forest, managed pastures, degraded pastures, and bare soil. The LULCC analysis was conducted using cross-tabulation matrices.

The sampling design, confusion matrices for each year of land use and land cover maps, and the accuracy of LULCC detection may be found in Silva et al. (2016).

4.2. Drivers of land change

Drivers represent the independent variables acting in land use and land cover change models (Hersperger et al., 2010). These models conceptually assume that the drivers induce the observed changes, and based on the results, drivers and land changes can be hypothesized. Census-based data and biophysical data (e.g., elevation) were set to input as LULCC model's independent variables. The independent variables were set to each respective time span. Supported by familiarity with the study area and FT theory, seventeen independent variables were selected for analysis (Table 1).

The *aspect*, *elevation* and *slope* were generated from the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) with horizontal resolution of 1″ (about 30 m). The soil map (Oliveira et al., 1999) was organized into five classes according to the Brazilian System of Soil Classification (EMBRAPA, 2006): Ultisols (Argissolos), Inceptisols (Cambissolos), Gleysols (Gleissolos), Oxisols (Latossolos) and Histosols (Organossolos).

The *proximity of forest* and *proximity of eucalyptus* were generated from the land use maps of 1985, 1995 and 2005. Binary maps were created for each class (forest and eucalyptus) and distance maps were calculated. The *proximity of roads* was calculated in relation to paved roads. To build this variable, three road maps for the same years were used. The road maps were created from files supplied by the National Department of Infrastructure and Transport (DNIT). Historical information about roads in Paraíba Valley and about the maps themselves were provided by the National Plan of Logistics and Transport (MT, 2012).

The spatial distribution of the information contained in each socioeconomic variable was performed on the municipal grid vector file, obtained from the website of the Brazilian Institute of Geography and Statistics (IBGE), and subsequently transformed to raster format (30 m of spatial resolution). The variable *farm credit* was generated by the sum of total accumulated credit in the period of change divided by the total area occupied by farms within each municipality (SAA/CATI/IEA, 1996, 2008). The *stocking rate* was built by dividing the total number of animals in each municipality by the total area occupied as pasturelands in the respective municipality, in the same year (number of animals in 1985/pasturelands in 1985). For *rural population density*, the total number of rural residents per municipality was divided by the total area occupied by farms within each respective municipality. The information about the total area occupied by farms within each municipality is provided by the 'Census of Agricultural Production Units of São Paulo State' project – LUPA (SAA/CATI/IEA, 1996, 2008). The other socioeconomic variables are expressed as their real values.

As inputs for the models, some variables were normalized (Eastman, 2012) (Table 1). For each period of change (1985–1995, 1995–2005, 2005–2011), we introduced in the models the independent variables regarding the date of commencement of the period, with the exception of *farm credit*.

4.3. Multi-layer perception neural network: LULCC model

Multi-layer perception models were used to associate changes of non-forest areas to forest (forest regeneration process) with drivers (Table 1). For this purpose, the land use land cover maps were converted into two classes: forest and non-forest (Fig. 2). We used the map of change from "non-forest to forest" for each time span as a dependent variable.

We chose the Multi-Layer Perception Neural Network (MLPNN) method because it facilitates integration between the dynamic interactions of anthropogenic variables with ecological characteristics of the environment (Lippitt et al., 2008). Machine learning methods such as neural networks favor the characterization of models where there are non-linear relationships between the set of variables (Lek and Guegan, 1999). The model MLPNN uses the Back-Propagation algorithm (Rumelhart et al., 1986), which has broad applicability in modeling studies of ecological relationships for predictive or exploratory purposes, especially where the response curves are non-linear (Olden and Jackson, 2001). For the present study, a multi-layer perception model was trained by the Back-Propagation (BPN) procedure, which is an artificial neural network with feed-forward using a BPN algorithm (Rumelhart et al., 1986; Lippitt et al., 2008; Conforti et al., 2014). Based on a recursive learning procedure, this algorithm uses a gradient descent of searching to minimize the model calibration errors (Kanellopoulos and Wilkinson, 1997).

The BPN algorithm works without parametric assumptions (Lippitt et al., 2008) and allows the characterization of models containing non-linear relationships and dependence within and between predictor variables, without explicit definition of these relationships (Lek and Guegan, 1999). This advantage allows increasing the prediction accuracy of these models compared to parametric techniques such as Logistic Regression models (Manel et al., 1999; Lippitt et al., 2008). The independent variables are used to model the historical process of change, and the accuracy of the model should be above 75% to be considered acceptable (Eastman, 2012). The parameters used for the MLPNN were: 50% of the dataset for training sample and 50% for validation; 10000 iterations; the time factor equal to 0.5; sigmoid constant at 1.

According to Eastman (2012), the Cramer's V test is an exploratory method to define the independent variables to use in a model. This test assesses the capacity or potential (power) of each explanatory variable in relation to the dependent variable. A Cramer's V value above 0.15 indicates that the variable have acceptable explanatory power and for this reason, should be maintained in the model, while if a variable have a Cramer's V value below 0.15, it should be excluded from the model (Eastman, 2012). Thus, for each period of change, all variables were tested and only those with values above 0.15 were selected as inputs for the land use and land cover change models.

5. Results

5.1. Land use and land cover changes

Findings for LULCC indicate strong dynamics for some cover classes but not others. The results of land use and land cover spatial distribution highlight the forest cover class (Atlantic Forest) as the one with the most significant rates of gain: 7.46%, 2.84% and 3.38% over the studied periods, respectively. The degraded pasture represented the land use class with largest reduction in area: −15.81% and it is the land use class that has contributed over 70% to the new forest cover areas. In the years of 1985 and 2011, the managed pastures occupied the same proportion of land use (around 27% of the total area). In the years of 1995 and 2005, managed pastures suffered reductions in area mostly replaced by forest cover. The increase of managed pastures between 2005 and 2011 occurred mostly over degraded pastures. Fig. 3 shows the area occupied by each land use and land cover class.

To understand the dynamics of LULCC it is necessary to assume that each class will swap over the years, meaning that whenever there is a decrease or increase of a class necessarily one or more classes should also suffer reductions or increases. The role of the

Table 1
Independent variables selected to study forest transition in the Paraíba Valley, São Paulo state, Brazil during the periods of 1985–1995, 1995–2005, and 2005–2011.

Variables	Description	Structure	Normalization	Source	Time range (year)
X_1	Aspect	Continuous	–	ASTER GDEM	–
X_2	Elevation (m)	Continuous	–	ASTER GDEM	–
X_3	Rural houses (no. of houses)	Continuous	square root	IBGE/SEADE[a]	1980–2010
X_4	Proximity of eucalyptus (m)	Continuous	natural log	Land Use Map	1985–2011
X_5	Proximity of forest (m)	Continuous	natural log	Land Use Map	1985–2011
X_6	Proximity of roads (m)	Continuous	natural log	DNIT/MT	–
X_7	Farm job (no. of jobs)	Continuous	square root	MTE/SEADE[a]	1991–2014
X_8	Soils (classes)	Categorical	evidence likelihood	IA/EMBRAPA[b]	–
X_9	Farm credit ($/ha)	Continuous	square root	BACEN/SEADE[a]	1985–2011
X_{10}	Formal job (no. of jobs)	Continuous	square root	MTE/SEADE[a]	1991–2014
X_{11}	Industry and commerce (no. of unities)	Continuous	square root	SE/SEADE[a]	1980–2014
X_{12}	Stocking rate (animal unit/ha)	Continuous	square root	IBGE[c]	1974–2014
X_{13}	Milk productivity (L/no. of animals)	Continuous	square root	IBGE[c]	1974–2014
X_{14}	Municipal revenue ($)	Continuous	square root	MF/SEADE[a]	1980–2011
X_{15}	Rural population density (people/ha)	Continuous	square root	IBGE/SEADE/SAA[a]	1980–2014
X_{16}	Slope (degree)	Continuous	–	ASTER GDEM	–
X_{17}	Protected areas	Binary	evidence likelihood	MMA[d]	–

[a] all data for the historical series were generated by public institutes of research and compiled by the State Foundation of Data Analysis System (*SEADE* https://www.seade.gov.br/ In: "população e estatísticas vitais").

[b] Oliveira et al. (1999).

[c] Brazilian Institute for Geography and Statistics (IBGE): http://www.sidra.ibge.gov.br/bda/acervo/acervo2.asp?e=v&p=PP&z=t&o=24 In: "pecuária".

[d] Brazilian Ministry of Environment: http://mapas.mma.gov.br/i3geo/datadownload.htm In: "áreas especiais".

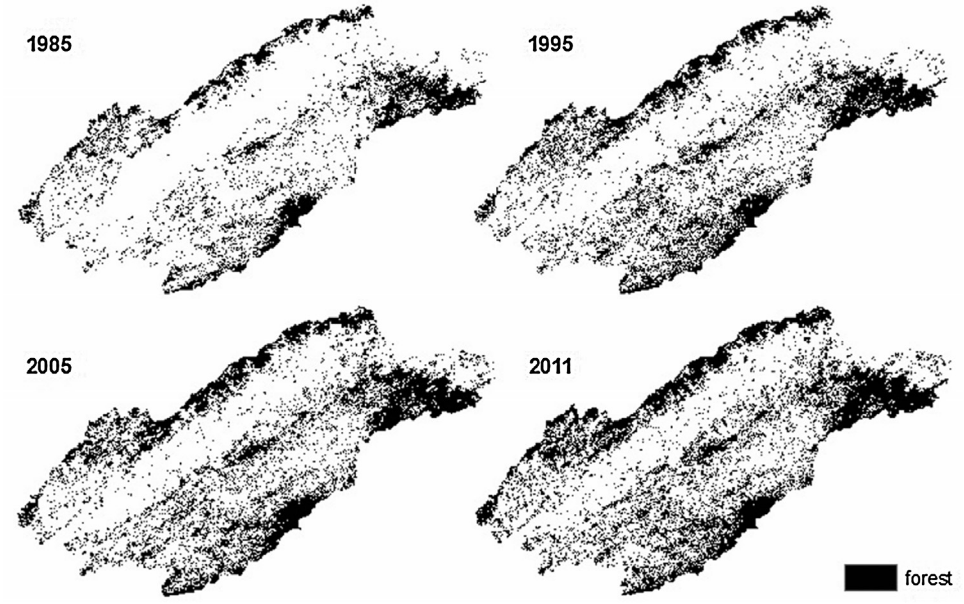

Fig. 2. Binary maps of forest and non-forest cover classes.

change matrix (Table 2) is to bring to light the dynamic swapping processes, and at what rates they occur between classes.

The change matrix shows a dynamic landscape with a strong relationship between the classes of managed pasture, degraded pasture and forest. According to the data (Table 2), in the three periods of change, the class of degraded pasture made the largest contribution to new areas of forest, and it also had intense swapping with managed pastures. This trend indicates the abandonment of former pasturelands (increase of degraded pastures areas) as the most influential factor to the FT in the study region. The eucalyptus plantations had 48% of its growth over degraded pastures and 30% over managed pasture. Between the classes with more significant contribution to deforestation are pasturelands and eucalyptus. In the years between 1985 and 2011 the urban areas increased 1.12%. According to the census data, in the early 1980s the rural population had decreased to 13.5%, and fell to 5.8% in 2010, while the urban population increased from 1,118,653 inhabitants in 1980 to 1,804,126 in 2010.

The agriculture class occupied a constant and small proportion of areas in 1985 and 2011, decreasing 2.31% during the first period of change, 1985–1995. The stability of agricultural areas occured especially in the floodplains of the Paraiba River occupied by rice farming.

The eucalyptus plantations in 1985, that corresponded to 2.58% (375 sq.km) of the Paraíba Valley, reached 6.15% (864 sq.km) in 2011. This land use inside the private lands of the forestry company operating in the region increased from 140 sq.km to 376 sq.km, while natural forest cover areas changed from 98 sq.km to 280 sq.km between 1985 and 2011 (Table 3).

The study region consists of 34 municipalities with numerous demographic and socioeconomic differences, and they exhibited different rates of forest gain and forest stability, as well as different dynamics in the eucalyptus land cover during the three periods

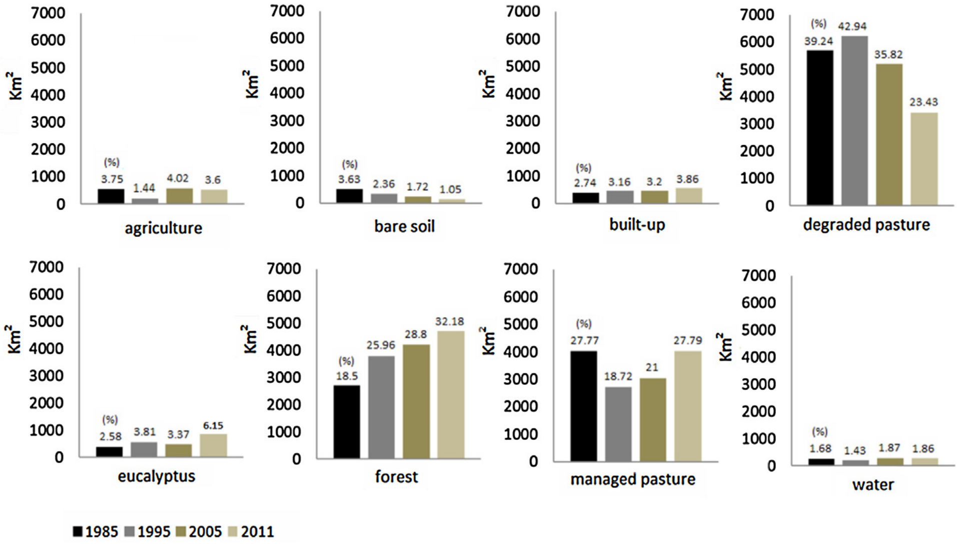

Fig. 3. Land use and land cover in the Paraíba Valley. The graphics show each class extension in km^2, and the percentage (%) of each class in relation to the other classes.

Table 2
Land use and land cover change matrix for the Paraiba Valley, São Paulo state, Brazil.

(sq.km)	1985							
1995	Degraded pasture	Agriculture	Managed pasture	Eucalyptus	Bare soil	Built-up area	Forest	Water
Degraded pasture	3290.58	229.09	1995.52	63.71	200.68	93.95	331.7	25.27
Agriculture	23.87	72.58	55.99	1.03	36.91	14.05	1.61	3.05
Managed pasture	887.75	47.97	1572.03	12.25	120.38	39.33	25.21	11.18
Eucalyptus	145.37	17.58	47.15	170.61	11.65	1.69	158.84	0.17
Bare soil	71.32	43.49	108.51	4.79	83.33	18.08	6.32	7.27
Built-up area	48.11	44.94	102.75	1.33	33.51	215.74	3.24	9.48
Forest	1219.41	82.83	140.26	119.28	34.59	10.28	2165.58	13.87
Water	6.03	5.78	6.74	2.02	6.55	5.04	3.13	173.56

(sq.km)	1995							
2005	Degraded pasture	Agriculture	Managed pasture	Eucalyptus	Bare soil	Built-up area	Forest	Water
Degraded pasture	3691.71	37.76	754.98	73.27	78.86	66.55	486.01	7.75
Agriculture	299.66	106.45	85.16	1.23	46.71	30.94	10.15	4.21
Managed Pasture	1137.86	18.31	1681.85	19.95	88.76	54.99	43.55	1.77
Eucalyptus	113.11	2.39	56.63	213.25	7.31	1.71	95.29	0.32
Bare soil	70.94	14.18	47.73	7.79	66.27	29.55	9.09	4.81
Built-up area	92.76	16.41	45.31	1.11	28.89	260.37	17.13	2.31
Forest	797.56	8.72	37.41	235.99	10.95	5.71	3098.42	5.78
Water	26.88	4.88	7.11	0.35	15.39	9.27	26.11	181.91

(sq.km)	2005							
2011	Degraded pasture	Agriculture	Managed pasture	Eucalyptus	Bare soil	Built-up area	Forest	Water
Degraded pasture	2467.98	62.24	499.57	23.72	32.49	18.79	289.16	6.59
Agriculture	182.99	194.38	59.84	4.88	20.77	36.38	16.06	7.05
Managed pasture	1425.86	251.65	2205.37	9.88	58.56	49.01	27.36	5.41
Eucalyptus	192.73	6.98	113.19	321.86	13.55	1.81	213.26	0.45
Bare soil	40.57	18.73	26.02	0.49	47.35	8.41	3.69	7.23
Built-up area	58.31	32.16	70.91	1.26	56.41	326.02	9.43	6.39
Forest	812.37	12.27	68.18	127.21	8.14	19.52	3636.15	18.17
Water	16.35	6.12	4.01	0.72	13.11	4.41	5.97	220.61

Table 3
Variation rates of LULC classes within private lands of the forestry company operating in Paraíba Valley. The private land areas total 817 sq.km[a].

	Land use and land cover classes (%)					
	Eucalyptus	Forest	Agriculture	Managed pasture	Degraded pasture	Soil
1985	17.17	12.03	3.31	25.43	38.01	3.19
1995	21.76	24.04	0.27	16.08	36.68	1.21
2005	26.07	31.25	0.79	12.15	26.07	1.28
2011	46.01	34.35	1.08	5.81	11.79	0.11

[a] the total area correspond to the Forest Management Plan of 2014 of the forestry company: http://www.fibria.com.br/shared/midia/publicacoes/plano_de_manejo_fibria_sp_2014_09_23.pdf.

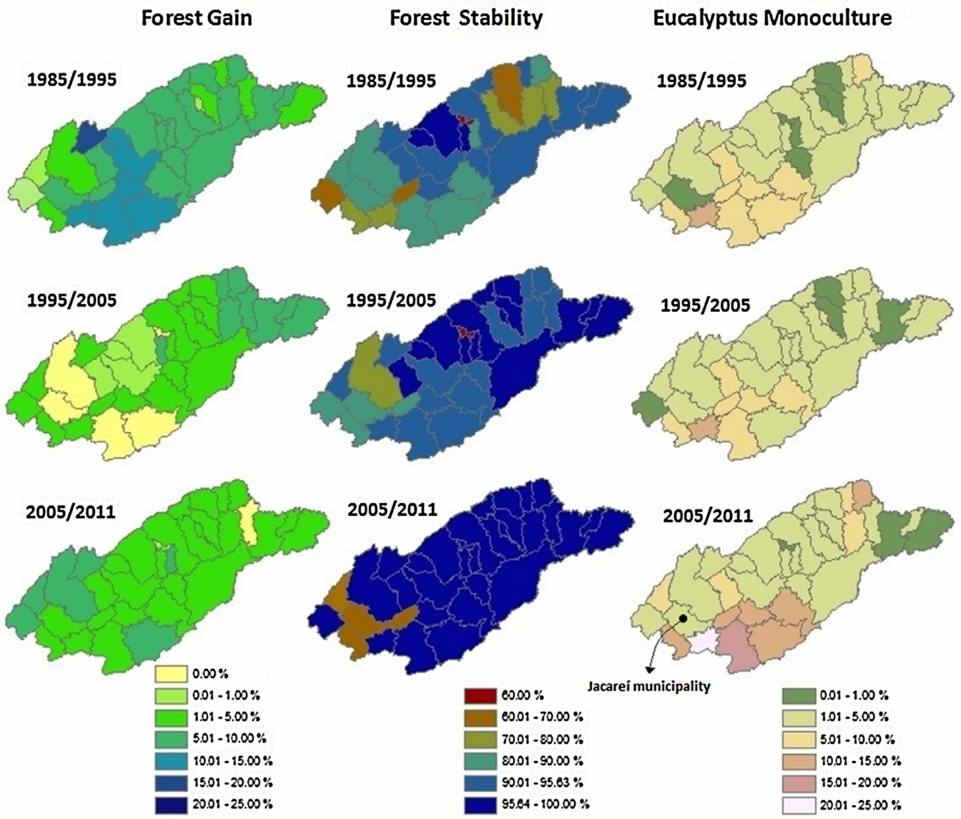

Fig. 4. Proportion of forest gain, forest stability, and eucalyptus monoculture plantations in the Paraiba Valley, Brazil. "Forest gain" maps represent the percentage of increase in forest cover in the period of change minus the rate of loss by deforestation. "Forest Stability" is the area of forest that remained stable throughout the period of change. The maps for "eucalyptus monoculture" represent the portion of this land use in each municipality. The spatial unit of the maps is the municipality.

of change. The highest concentration of eucalyptus plantations is in the municipalities closer to Jacareí (Fig. 4), where stands the pulp and paper industrial facility. The highest rates of forest gain occurred during the first period of change and vary for each municipality.

Fig. 4 also reveals patterns of forest cover dynamics, indicating different patterns of land changes, affected by the diversity of biophysical and socioeconomic factors present in each municipality. The maps also show a tendency towards forest cover stability in 2005–2011.

5.2. LULCC models and drivers

The results of Cramer's V test reveal the explanatory power of the independent variables for each period of change (Table 4). The results presented in Table 4 show variations in the number of variables with minimal explanatory power for each period indicating that the process under study is dynamic and without a linear or predictable relationship with the same variables during the time series.

The IDRISI software (version 17.01) used for data modeling presents an open version of the results generated by the method of multi-layer perception in the module "Land Change Modeler". Through the measures of accuracy and rate of learning, the MLPNN evaluates the sensitivity of the model taking into account the independent variables one by one. Thus, the MLPNN is able to register the importance (influence order) of each driver in relation to the dependent variable (Table 5) and its ability to model the process of change.

Table 4
Results of Cramer's V test for the set of independent variables.

Independent variables	Cramer's V		
	1985/1995	1995/2005	2005/2011
(X_1) aspect	0.1586	0.1326	0.1167
(X_2) elevation	0.2887	0.3038	0.2997
(X_3) rural houses	0.1537	0.1676	0.1536
(X_4) proximity of eucalyptus	0.1083	0.2755	0.1820
(X_5) proximity of forest	0.4624	0.6056	0.5469
(X_6) proximity of roads	0.1889	0.2050	0.2358
(X_7) farm job	0.1339	0.1559	0.1729
(X_8) soils	0.2081	0.2274	0.2189
(X_9) farm credit	0.1435	0.1590	0.1643
(X_{10}) formal job	0.1238	0.1211	0.1367
(X_{11}) industry and commerce	0.1319	0.1313	0.1624
(X_{12}) stocking rate	0.1239	0.1645	0.1565
(X_{13}) milk productivity	0.1432	0.1742	0.1309
(X_{14}) municipal revenue	0.1315	0.1257	0.1389
(X_{15}) rural population density	0.1271	0.1470	0.1347
(X_{16}) slope	0.1592	0.1606	0.1597
(X_{17}) protected areas	0.1198	0.1168	0.1342

Table 5 shows the results of the models of change with the variables accepted by Cramer's V test for each period. The influence order (IO) ranks the order of variables from 1 for the most influential and so on. Thus, as observed (Table 5), the *proximity of forest* played the major role to the increase of forest cover in all periods (1985–1995; 1995–2005; and 2005–2011). On the other hand, the *proximity of roads* had low influence for the increase of forest cover indicating that the likelihood of forest cover regeneration increases with increasing distance from roads. The following subsections present key findings for each period of change showing that the drivers of FT shift their influence over time.

Table 5

Results of the "Land Change Modeler" by the MLPNN method. The "IO" column in the table represents the influence order of each independent variable for the prediction of the model relative to the dependent variable (non-forest to forest). In ascending scale, the "IO" column shows the most influential driving force with the value 1. The last row ("all") means the general result for the model.

Variables	1985–1995		IO	1995–2005		IO	2005–2011		IO
	Accuracy (%)	Skill Measure		Accuracy (%)	Skill Measure		Accuracy (%)	Skill Measure	
(X_1) aspect	70.40	0.4079	2	–	–	–	–	–	–
(X_2) elevation	75.74	0.5149	4	81.99	0.6399	5	77.73	0.5547	5
(X_3) rural houses	75.85	0.5171	6	81.47	0.6294	3	77.83	0.5567	6
(X_4) proximity of eucalyptus	–	–	–	80.21	0.6041	2	77.74	0.5494	2
(X_5) proximity of forest	66.28	0.3257	1	63.70	0.2739	1	62.07	0.2413	1
(X_6) proximity of roads	75.86	0.5173	7	82.38	0.6477	11	78.08	0.5615	9
(X_7) farm job	–	–	–	82.28	0.6457	10	77.73	0.5547	4
(X_8) soils	75.84	0.5169	5	82.20	0.6441	8	78.11	0.5621	10
(X_9) farm credit	–	–	–	81.92	0.6385	4	78.04	0.5607	8
(X_{11}) industry and commerce	–	–	–	–	–	–	77.66	0.5533	3
(X_{12}) stocking rate	–	–	–	82.03	0.6407	7	77.94	0.5587	7
(X_{13}) milk productivity	–	–	–	82.01	0.6403	6	–	–	–
(X_{16}) slope	75.46	0.5093	3	82.23	0.6447	9	78.18	0.5636	11
All	76.18	0.5237	–	82.33	0.6467	–	78.10	0.5619	–

5.2.1. *First period of change (1985–1995)*

The highest rate of forest net gain was observed during this period, 7.46% or an area equivalent to 1082 sq.km. The *aspect* showed a strong relationship in the prediction of change from non-forest to forest. It was observed that 34% of forest gain occurred on the North face of the Valley's relief while 56% over the South face, and 9% on flat areas. The *slope* is the third variable in order of influence in the MLPNN model. In slopes of 20% to 75%, the forest cover increased 75.82% and indicates likelihood of forest regeneration over slopes less suitable for agricultural practices (see Supplementary materials).

5.2.2. *Second period of change (1995–2005)*

The *proximity of forest* was the driver with greater influence on the forest regeneration process as observed in the first period. Unlike the first period of change, however, the *aspect* did not have enough explanatory power, therefore it was not included in the model. In this period, new socioeconomic variables presented explanatory power above 0.15 and were incorporated into the model.

The *proximity of eucalyptus* was the second variable in the influence order on the model, suggesting a tendency of forest cover to increase near eucalyptus plantations. With approximately 80,851 ha of their own lands, the largest forestry company operating in the Paraíba Valley, had approximately 44% of its total area covered by eucalyptus plantations between the years of 1995 and 2005 while the forest cover increased from 24.04% to 31.25% in the same period (Table 3).

In this period, two socioeconomic variables were highlighted in the order of influence of drivers of the model: *rural houses* and *farm credit*. It was observed for the *rural houses* that 34% of new forest cover areas occurred in seven municipalities with the number of permanent rural dwelling below average among the 34 municipalities. It was observed that 54% of the new forest cover areas occurred in ten municipalities with *farm credit* below the average for municipalities in the Paraíba Valley. For example, the municipality of Cunha, with the highest rate of change from non-forest to forest, had one of the lowest farm credit allocations suggesting the following trend: the smaller the farm credit in a particular municipality, the greater the likelihood of forest cover increase in the same period (see Supplementary materials).

5.2.3. *Third period of change (2005–2011)*

Between the years of 2005 and 2011 the *proximity of eucalyptus* and *proximity of forest* kept their importance on the dynamic process of forest regeneration. However, at this time, there were changes in the order of socioeconomic variables. According to the result of MLPNN, the third variable with high influence on the changes was *industry and commerce*. The analysis indicates that 9 of the 34 municipalities of the Paraíba Valley concentrated 85% of all industries and commercial establishments in 2005. Regarding the total forest increase between 2005 and 2011, 33.5% occurred in these 9 municipalities. The proportion of forest increasing in these municipalities was 3.8%, and 1.9% in the other 25 municipalities. It was observed that 39% of the forest cover growth occurred in 19 municipalities with below average availability of farm jobs. Thus, the rate of forest gain was equivalent to 2% for each municipality with less than 272 formal jobs in agriculture, while for those above average, it was 4% (see Supplementary materials).

6. Discussion

The discussion section is organized following each period of analysis as presented in the Results Section 5. The most influential independent variables to the FT process in each period of analysis is discussed. As the LULCC models indicated, the growth of new forest cover areas are related to many drivers affecting each period of land use and land cover changes differently. After discussing LULCC models in each time period, we provide a discussion about the implications of the model's results to FT and how policy makers and society can benefit through this study in drafting land use and forest conservation policies.

6.1. *Period of 1985–1995*

The remaining forest cover areas are critical to the Atlantic Forest biome regeneration, as already observed by Lira et al. (2012). In this case, the recovery of the forest cover in the Atlantic Forest biome in the Paraíba Valley is strongly associated with the proximity to forest remnants.

The relationship between the FT and *aspect* is explained by the studies of Rosenberg et al. (1983); Bale et al. (1998); and Mello (2009) that have shown the differences of solar radiation over the southern hemisphere, pointing the north faces of the southern hemisphere as having greater insolation and consequently considered more productive for agricultural production. Thus, the increase of forest cover areas had a strong relationship with degraded pastures in the "opposite-faces", which are the sections of land surface located in the South face of the Paraíba Valley landscape, which are less suitable for agriculture than the North face. This phenomenon, which is related to the abandonment of land use, can be partially explained by the farmer's decision for the best lands to be dedicated for agricultural use, and in part by the role of the São Paulo State Decree, n^0 28848 of 1988, that banned the practice of burning to prevent the use of fire for the control and management of pasturelands. According to Silva (2015), this policy had impact on the maintenance of grasslands on the "opposite-faces", where the cost-benefit for the management of pastures without the use of fire and just by manual or mechanical weeding, became disadvantageous, leading to the abandonment of many of these areas. As a result of the land abandonment in these areas, the forest natural regeration process took over the areas.

The influence of the *slope* in the model's result has an intrinsic relation to the Paraíba Valley landscape, characterized as a "sea of hills" (Ab'Saber, 2003). The slopes of the Valley have a strong influence on the decision making process for land use and favors conservation on the most steep slopes, less suitable for agricultural practices including mechanization, irrigation and grazing (Mello, 2009; Silva, 2015).

The first period of analysis revealed a FT process influenced predominantly by biophysical features of the Valley characterized as marginal lands for agricultural use. The control of burning practices had strong influence to release marginal lands for native vegetation regeneration once the cost-benefit to manage these areas with manual weeding or by mechanization where possible did not worth the investment. The reason for the highest forest recovery rate during this period is related to the likelihood of land abandonment of marginal lands in steep slopes reinforced by agricultural management policies.

6.2. *Period of 1995–2005*

During this period, the *proximity of eucalyptus* becomes influential on the FT process, the same period that the Valley's forestry company turned its production to the international market, and started to trade shares on the stock exchange of New York. Farinaci et al. (2013) call attention to the globalized market for eucalyptus production in the Paraíba Valley, which is focused on international trade, and follows strict international protocols such as the Forest Stewarship Council (FSC) certification program and the Brazilian Program of Forest Certification (Cerflor), both of which had positive impacts on the conservation of Atlantic Forest remnants.

The LULCC analysis inside rural properties with eucalyptus cultivation showed the following trends: as the eucalyptus plantation is allocated in the private lands of the forestry company, the land use changes from pastureland to eucalyptus, predominantly. This change process, driven by land grabbing, displaces former local farmers and the company starts to produce eucalyptus as an agroindustrial system. As a result, less suitable lands are made available (usually occupied by pasture) for environmental compensation (through forest restoration projects) or abandoned for natural forest regeneration. As Table 3 shows, the allocation of eucalyptus in the rural property to provide raw material for the cellulose pulp agroindustrial system fosters the increase of natural forest cover areas.

In regard to the likelihood of forest cover increase where we observed small flows of farm credit, as in the municipality of Cunha, we noted that in Brazil, the 1990s was marked by a shift in agricultural regional dynamics influenced by a new agricultural credit policy. From this decade on, the funding policies cease to be a state priority and the market begins to drive access to credit. This change leads to the consolidation of the major producers, new agricultural areas are developed through mechanization, and it promoted uneven regional distribution of credit in the country. As result, the Brazilian rural sector faced scarcity of rural credit, falling from 30 billion Reais (Brazilian currency) in 1980 to 10 billion in 1997 (Padilha and Medeiros, 2010). Regions with a predominance of small-scale agriculture, low technological development and low profitability, were most affected. In the Paraíba Valley, these changes led to decapitalization of small farmers since the 1990s, leading them to abandon less productive and unsuitable areas, with a resulting return of natural vegetation.

6.3. *Period of 2005–2011*

During the third period of change, the FT process was influenced by a different set of socioeconomic variables. The concentration of industries and commerce in a specific set of municipalities resulted in a more than 2-fold gain in the rates of forest cover. This result provides support for FT theory (Rudel et al., 2005, 2010), as the economic development, which in this case is represented by industrialization and commerce, is a vector for the process of forest vegetation's return. Studies on FT have demonstrated the influence of economic development (e.g., process of industrialization) and consequent socioeconomic transformations of rural areas as a driver in the increase of forest cover areas (Foster et al., 1998; Mather et al., 1999; Evans et al., 2005).

From the result and socioeconomic information about the region, it is clear that the sectors of agribusiness and rural tourism (rural tourism, ecotourism and historical tourism) may have played a significant role in explaining the relationship between farm jobs and FT, because they require employment and generate income, thereby providing opportunity costs for the local population in rural areas through non-agricultural activities, and to stimulate the restoration and conservation of natural environments (Couto and Serra, 2011; Izique, 2012; Roque, 2013). This result indicates a trend of higher increase of forest in the municipalities with the largest number of farm jobs.

In São Paulo state, in 2009, 79% of rural income came from non-agricultural activities (Izique, 2012). The development of formal job activities in rural areas unlinked to the livestock and agriculture practices, and more focused on agribusiness, forestry, tourism and leisure sectors, may reflect the intensification or abandonment of agricultural lands. The tourism and leisure sectors also stimulate conservation practices such as environmental restoration and establishment of agroforestry systems, both with favorable consequences on forest cover.

6.4. *Drivers change over time: implications to regional forest transitions*

As noted in Table 5, the drivers shift their influence on the FT during the three periods of analysis. The biophysical factors related to agricultural land use are the most prevalent during early stages of the FT. From our finds, this early period of change (1985–1995) is characterized by forest scarcity and widespread availability of marginal land areas, favored by the enforcement of restrictive land management policies and the prohibition of burning. Thereafter, if forest cover continues to expand, socioeconomic drivers come to have influence from a certain stage of saturation of marginal lands already occupied by new forest cover areas, that corresponds to the model's second and third periods of change. At this time, environmental protection policies, as well as monitoring deforestation and the protection of areas in vegetation succession process, begin to play important roles on the FT trajectory. It is important to mention that the evolution and development of these policies are also a reflection of the landscape changes that arouse the interest and attention of the population, scientific community and policy makers around the dicussions about environmental conservation. From the typical FT theory curve (Rudel et al., 2005), the first period of change (1985–1995) corresponds to the Time 1 ("bottom") of the curve when the gain of forest cover (secondary forests) overcome losses in old forest remmants. The following periods (1995–2005 and 2005–2011) are allocated to the “right” of the curve when the forest cover is expanding over time.

This result has important implications for the effective formulation and implementation of environmental policies and land use management and planning. In our FT scenario, the first period of changes is characterized by a region where the population is densely concentrated in urban areas with large amounts of uninhabited rural areas, with the predominance of the smallholder farm sector and scarce remnants of tropical forest.

At this point, FT processes can be induced by strong policies of land use restriction in unproductive lands such as mountainous areas or areas remote from highways and urban centers. These policies may target the areas of restriction previously defined in agricultural technical reports, by ecological-economic zoning, or also by policies that ban certain management practices, such as mechanization on steep slopes or the use of fire for agricultural management which finally, make economically unfeasible the use of less productive areas.

As these areas are abandoned and natural regeneration processes are initiated, new policies aimed at the protection and surveillance of remaining areas of natural vegetation and in regeneration process as well, monitoring of potential environmental crime offences, becomes necessary. At this time, when marginal lands are already abandoned and replaced by secondary forest succession, if the FT continues, it goes in subsequent periods (1995–2005 and 2005–2011) that occur more slowly over time on degraded lands with reasonable agricultural potential, influenced by socioeconomic factors, as *(a)* the influence of conservation ideas (e.g., FSC certification in the eucalyptus production system, and rural-environmental tourism), *(b)* by the rigidity in the distribution of State credit for agribusiness (e.g., farm credit), *(c)* the shortage of rural workers influenced by the demand for labor in urban centers, and *(d)* the development of new agro producer regions, which can become more cost-effective alternative to the production of commodities, as seen with the eucalyptus production system, which in recent years stagnated in the Paraíba Valley and has developed strongly in the Midwest region of Brazil (Silva, 2015).

The Valley’s FT suffered a slowdown along time and according to the results from LULCC models, we interpret this temporal dynamic as shifts in drivers behind forest recovery. Therefore, the shift from biophysical factors to socioeconomic factors implies that sustaining forest recovery requires shifts in policies over time. These finds make clear that policy makers need to be aware of the spatio-temporal processes of land transitions, once certain policies lose effectiveness over time while new policies and institutions emerge that are more suitable to fit temporal and regional demands.

7. Conclusions

The results observed in Table 2 show that LULCC in the Paraíba Valley had consequences on the increase of forest cover areas. Among the seventeen independent variables selected for the study, fourteen presented explanatory power above 0.15. For the three periods of analysis, different intensities of influence from these variables on the dependent variable (non-forest to forest) were observed. We conclude that there is not a single major driver on the process of change modeled, but a group of them, interacting at different levels and varying in each period– not surprising in a complex and dynamic system such as this one. As the FT theory has demonstrated, there is no single FT pathway operating over time on forest cover dynamics worldwide. The most likely expectation is that one pathway can have several overlapping pathways changing over time at regional scales.

Topography had a strong influence on the dynamics of forest cover between 1985 and 1995, but lost influence in later periods. On the other hand, socioeconomic variables that showed no significant influence on forest cover in the early period, became more influential between 1995 and 2011. Such information shows that in the Paraíba Valley, areas most susceptible to Atlantic Forest regeneration are those with topography less favorable for agricultural and livestock use. As these areas are replaced by forest cover, these biophysical variables become less significant giving way to other social and economical factors, which act at local scales (e.g., municipality). Therefore, the shift from biophysical factors to socioeconomic factors implies that sustaining FT may require shifts in policies and rules over time.

Acknowledgments

We gratefully acknowledge the funding support by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) (FAPESP), processes 2011/13568-0 and 2013/09243-3. We also acknowledge the help and support provided by the Center for Environmental Studies (NEPAM/UNICAMP), EMBRAPA (Brazilian Agricultural Research Corporation), and the Center for Global Change and Earth Observations (Michigan State University), as well as Dr. William J. McConnell for the valuable criticisms and experience. We also acknowledge the reviewer for the comments and suggestions that have improved the quality of the manuscript. The opinions expressed herein are the sole responsibility of the authors.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2016.07.021.

References

Ab’Saber, A.N., 2003. Os domínios de natureza no Brasil: potencialidades paisagísticas, 6ªed. Ateliê Editorial, São Paulo.

Alves, E., Souza, G.S., Marra, R., 2011. Êxodo e sua contribuição à urbanização de 1950 a 2010. Política Agrícola 2, 80–88, Available at: https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/910778/1/Exodoesuacontribuicao.pdf.

Bale, C.L., Williams, J.B., Charley, C.L., 1998. The impact of aspect on forest structure and floristics in some Eastern Australian sites. For. Ecol. Manag. 110, 363–377, http://dx.doi.org/10.1016/S0378-1127(98)00300-4.

Baptista, S.R., 2008. Metropolization and forest recovery in southern Brazil: A multiscale analysis of the Florianópolis City-Region, Santa Catarina State, 1970–2005. Ecol. Soc. 13, 5, Available at: http://www.ecologyandsociety.org/vol13/iss2/art5/.

Beilin, R., Lindborg, R., Stenseke, M., Pereira, H.M., Llausàs, A., Slätmo, E., Cerqueira, Y., Navarro, L., Rodrigues, P., Reichelt, N., Munro, N., Queiroz, C., 2014. Analysing how drivers of agricultural land abandonment affect biodiversity and cultural landscapes using case studies from Scandinavia, Iberia and Oceania. Land Use Policy 36, 60–72, http://dx.doi.org/10.1016/j.landusepol.2013.07.003.

Bieling, C., Plieninger, T., Schaich, H., 2013. Patterns and causes of land change: empirical results and conceptual considerations derived from a case study in the Swabian Alb, Germany. Land Use Policy 35, 192–203, http://dx.doi.org/10.1016/j.landusepol.2013.05.012.

Boffi, S.A.N.O., Ricci, F., Oliveira, E.A.A.Q., 2006. Análise histórica da região do Vale do Paraíba como atrativo para a implantação da indústria de base (1930–1980). Rev. Univap 13, 3059–3063, Available at: http://www.inicepg.univap.br/cd/INIC_2006/epg/06/EPG00000542_ok.pdf.

Borgonovi, M., Chiarini, J.V., Amaral, A.Z., Coelho, G.S., Oliveira, D.A., 1967. Cobertura Vegetal do Estado de São Paulo. Bragantia 26, 95–102, Available at: http://www.scielo.br/pdf/brag/v26nunico/06.pdf.

Brandão, L.F., 2012. Relatório de sustentabilidade 2011. FIBRIA, São Paulo.

Brito, F., 2006. O deslocamento da população brasileira para as metrópoles. Estud. Av. 20, 221–236, http://dx.doi.org/10.1590/S0103-40142006000200017.

Calixto, J.S., Ribeiro, A.E.M., 2007. Três olhares sobre o reflorestamento: a percepção de atores sociais sobre a monocultura de eucalipto no Alto Jequitinhonha. MG. Organ. Rurais Agroind. 9, 437–450, Available at: http://revista.dae.ufla.br/index.php/ora/article/view/107.

Chavez, P.S., 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sens. Environ. 24, 459–479, http://dx.doi.org/10.1016/0034-4257(88)90019-3.

Conforti, M., Pascale, S., Robustelli, G., Sdao, F., 2014. Evaluation of prediction capability of the artificial neural networks for mapping landslide susceptibility in the Turbolo River catchment (northern Calabria, Italy). Catena 113, 236–250, http://dx.doi.org/10.1016/j.catena.2013.08.006.

Couto, M.F.R., Serra, E., 2011. Vale do Paraíba: da economia cafeeira à sustentável. Revista Geográfica de América Central 2, 1–15, Available at: http://www.revistas.una.ac.cr/index.php/geografica/article/view/2376.

Dean, W., 1996. A Ferro e Fogo: História de uso e ocupação da Mata Atlântica. Cia. das Letras, São Paulo.

Drummond, J.A., 1997. Devastação e preservação ambiental: os parques nacionais do Estado do Rio de Janeiro. EDUFF, Niteroi.

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), 2006. Serviço Nacional para Pesquisa e Conservação de Solos: Sistema Brasileiro de Conservação de Solos. EMBRAPA, Rio de Janeiro.

Eastman, J.R., 2012. IDRISI Selva Tutorial: Manual Version 17. Clark Labs & IDRISI Production, Worcester.

Evans, T.P., Munroe, D.K., Parker, D.C., 2005. Modeling land-use/land cover change: exploring the dynamics of human-environment relationships. In: Moran, E.F., Ostrom, E. (Eds.), Seeing the Forest and Trees: Human-Environment Interactions in Forest Ecosystems. MIT Press, Cambridge, pp. 187–213.

FAO (Food and Agriculture Organization of the United Nations), 2011. State of the World's Forests. FAO, Rome.

Farinaci, J.S., Ferreira, L.C., Batistella, M., 2013. Forest transition and ecological modernization: eucalyptus forestry beyond good and bad. Ambient. Soc. XVI, 25–44, http://dx.doi.org/10.1590/S1414-753x2013000200003.

Farinaci, J.S., 2012. As Novas Florestas do Estado de São Paulo: Um Estudo Multiescala sob a Perspectiva da Teoria da Transição Florestal (Tese de Doutorado). UNICAMP/IFCH, Campinas, Available at: http://www.bibliotecadigital.unicamp.br/document/?code=000857552&opt=3.

Ferreira, G.M.V., Oliveira, L., Talamini, E., 2006. Posicionamento Estratégico das Cooperativas Agropecuárias de Leite: O Caso da Cooperativa de Lorena e Piquete no Vale do Paraíba. In: Presented at the XLIV SOBER, Administração Rural e Gestão do Negócio, Fortaleza, Available at: http://purl.umn.edu/149553.

Foster, D.R., Motzkin, G., Slater, B., 1998. Land-use history as long-term broad-scale disturbance: regional forest dynamics in central new england. Ecosystems 1, 96–119, http://dx.doi.org/10.1007/s100219900008.

Freitas, J.C., 2008. A Política Agrícola do Regime Militar de 1964: aspectos jurídicos, financeiros e socioeconômicos. (Dissertação de Mestrado). UNIFOR/CCJ, Fortaleza, Available at: http://www2. unifor.br/tede//tde_busca/arquivo.php?codArquivo=786431.

Griffiths, P., Kuemmerle, T., Kennedy, R.E., Abrudan, I.V., Knorn, J., Hostert, P., 2012. Using annual time-series of Landsat images to assess the effects of forest restitution in post-socialist Romania. Remote Sens. Environ. 118, 199–214, http://dx.doi.org/10.1016/j.rse.2011.11.006.

Hecht, S.B., Kandel, S., Gomes, I., Cuellar, N., Rosa, H., 2006. Globalization, forest resurgence, and environmental politics in El Salvador. World Dev. 34, 308–323, http://dx.doi.org/10.1016/j.worlddev.2005.09.005.

Hersperger, A.M., Gennaio, M.P., Verburg, P.H., Bürgi, M., 2010. Linking land change with driving forces and actors: four conceptual models. Ecol. Soc. 15, 1, Available at: http://www.ecologyandsociety.org/vol15/iss4/art1/.

IBGE (Instituto Brasileiro de Geografia e Estatística), 1950. Censo Demográfico: 1950. IBGE, Rio de Janeiro.

Itani, M.R., Barros, C.M., Figueiredo, F.E.L., Andrade, M.R.M., Mansor, M.T.C., Mangabeira, R.L., Carvalho, V.S. (Eds.), 2011. SMA/CPLA, São Paulo.

Izique, C.O., 2012. Brasil rural não é só agrícola. In: Pesquisa Fapesp (Special edition)., pp. 202–207, Available at: http://revistapesquisa.fapesp.br/2012/08/22/o-brasil-rural-n%C3%A3o-%C3%A9-s%C3%B3-agr%C3%ADcola/.

Kanellopoulos, I., Wilkinson, G.G., 1997. Strategies and best practice for neural network image classification. Int. J. Remote Sens. 18, 711–725, http://dx.doi.org/10.1080/014311697218719.

Lambin, E.F., Meyfroidt, P., 2010. Land use transitions: socio-ecological feedback versus socio-economic change. Land use policy 27, 108–118, http://dx.doi.org/10.1016/j.landusepol.2009.09.003.

Lambin, E.F., Geist, H.J., Lepers, E., 2003. Dynamics of land use and land cover change in tropical regions. Annu. Rev. Environ. Resour. 28, 205–241, http://dx.doi.org/10.1146/annurev.energy.28.050302.105459.

Lek, S., Guegan, J.F., 1999. Artificial neural networks as a tool in ecological modeling, an introduction. Ecol. Model. 120, 65–73, http://dx.doi.org/10.1016/S0304-3800(99)00092-7.

Lima, A.R., Capobianco, J.P.R., 1997. Mata Atlântica: avanços legais e institucionais para sua conservação. ISA, São Paulo.

Lippitt, C.D., Rogan, J., Toledano, J., Sangermano, F., Eastman, J.R., Mastro, V., Sawyer, A., 2008. Incorporating anthropogenic variables into a species distribution model to map gypsy moth risk. Ecol. Model. 210, 339–350, http://dx.doi.org/10.1016/j.ecolmodel.2007.08.005.

Lira, P.K., Tambosi, L.R., Ewers, R.M., Metzger, J.P., 2012. Land-use and land-cover change in Atlantic Forest landscapes. For. Ecol. Manag. 278, 80–89, http://dx.doi.org/10.1016/j.foreco.2012.05.008.

Lu, D., Weng, Q., 2007. A survey of image classification methods and techniques for improving classification performance. Int. J. Remote Sens. 28, 823–870, http://dx.doi.org/10.1080/01431160600746456.

MMA (Ministério do Meio Ambiente), 2008. Instrução Normativa no. 06, de 23 de setembro de 2008. Accessed February 2016 at: http://www.mma.gov.br/estruturas/179/_arquivos/179_05122008033615.pdf.

MT (Ministério dos Transportes), 2012. Plano Nacional de Logística e Transportes—PNLT. MT, Brasília.

Machado, A.M.B., Drummond, G.M., Paglia, A.P., 2008. Livro vermelho da fauna brasileira ameaçada de extinção, 1 ed. MMA & Fundação Biodiversitas, Brasília.

Manel, S., Dias, J., Ormerod, S.J., 1999. Comparing discriminant analysis, neural networks and logistic regression for predicting species distributions: a case study with a Himalayan river bird. Ecol. Model. 120, 337–347, http://dx.doi.org/10.1016/S0304-3800(99)00113-1.

Mather, A.S., Fairbairn, J., Needle, C.L., 1999. The course and drivers of the forest transition: the case of France. J. Rural Stud. 15, 65–90, http://dx.doi.org/10.1016/S0743-0167(98)00023-0.

Mello, T.F., 2009. Estrutura da vegetação, cobertura florestal e preferências de uso da paisagem associadas a vertentes: as quase-florestas de São Luiz do Paraitinga (SP). (Dissertação de Mestrado). USP/IB, São Paulo, Available at: http://www.teses.usp.br/teses/disponiveis/41/41134/tde-19042010-105930/pt-br.php.

Meyfroidt, P., Rudel, T.K., Lambin, E.F., 2010. Forest transitions, trade, and the global displacement of land use. Proc. Natl. Acad. Sci. U. S. A. 107, 20917–20922, http://dx.doi.org/10.1073/pnas.1014773107.

North, M., Brough, A., Long, J., Collins, B., Bowden, P., Yasuda, D., Miller, J., Sugihara, N., 2015. Constrains on mechanized treatment significantly limit mechanical fuels reduction extent in the sierra nevada. J. For. 113, 40–48, http://dx.doi.org/10.5849/jof.14-058.

Olden, J.D., Jackson, D.A., 2001. Fish-habitat relationships in lakes: gaining predictive and explanatory insight using artificial neural networks. Trans. Am. Fish. Soc. 130, 878–897, http://dx.doi.org/10.1577/1548-8659(2001)130<0878:FHRILG>2.0.CO;2.

Oliveira, J.B., Camargo, M.N., Rossi, M., Calderano Filho, B., 1999. Mapa pedológico do Estado de São Paulo: legenda expandida. IAC/EMBRAPA-Solos, Campinas.

Padilha, W., Medeiros, M.C., 2010. As Mudanças Recentes no Crédito Rural e a Dinâmica Regional da Agricultura Brasileira. In: Presented at the XV ENG: Crise, práxis e autonomia, Porto Alegre, Available at: www.agb.org.br/evento/download.php?idTrabalho=1474.

Perz, S.G., Skole, D.L., 2003. Secondary forest expansion in the Brazilian Amazon and the refinement of forest transition theory. Soc. Nat. Resour. 16, 277–294, http://dx.doi.org/10.1080/08941920390178856.

Pontius, R.G., Millones, M., 2011. Death to Kappa: birth of a quantity disagreement and allocation disagreement for accuracy assessment. Int. J. Remote Sens. 32, 4407–4429, http://dx.doi.org/10.1080/01431161.2011.552923.

Prishchepov, A.V., Radeloff, V.C., Baumann, M., Kuemmerle, T., Müller, D., 2012. Effects of institutional changes on land use: agricultural land abandonment during the transition from state-command to market-driven economies in post-Soviet Eastern Europe. Environ. Res. Lett. 7, 024021, http://dx.doi.org/10.1088/1748-9326/7/2/024021.

Queiroz, L.R.S., Barrichelo, L.E.G., 2008. A celulose de Eucalipto: uma oportunidade brasileira. Avisbrasilis, Vinhedo.

Queiroz, C., Beilin, R., Folke, C., Lindborg, R., 2014. Farmland abandonment: threat or opportunity for biodiversity conservation? A global review. Front. Ecol. Environ. 12, 288–296, http://dx.doi.org/10.1890/120348.

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M., 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv. 142, 1141–1153, http://dx.doi.org/10.1016/j.biocon.2009.02.021.

Ricci, F., 2008. A economia cafeeira no vale do Paraíba paulista na República velha: Uma avaliação. Rev. Bras. Gest. e Desenvolv. Reg. 4, 105–117, Available at: http://www.rbgdr.net/revista/index.php/rbgdr/article/view/156.

Rodrigues, R.R., Gandolfi, S., 2007. Regrowth actions. In: Rodrigues, R.R., Martins, S.V., Gandolfi, S. (Eds.), High Diversity Forest Regrowth in Degraded Areas. Science, New York, pp. 77–102.

Roque, A., 2013. Estudo Preliminar da Cadeia Produtiva: Turismo Rural Brasil. IICA Brasil, Brasília.

Rosenberg, N.J., Black, B.L., Verma, S.B., 1983. Microclimate: the Biological Environment, 2nd edition. John Wiley & Sons, Chichester.

Rudel, T.K., Coomes, O.T., Moran, E., Achard, F., Angelsen, A., Xu, J., Lambin, E., 2005. Forest transitions: towards a global understanding of land use change. Glob. Environ. Chang. 15, 23–31, http://dx.doi.org/10.1016/j.gloenvcha.2004.11.001.

Rudel, T.K., Schneider, L., Uriarte, M., 2010. Forest transitions: an introduction. Land Use Policy 27, 95–97, http://dx.doi.org/10.1016/j.landusepol.2009.09.021.

Rumelhart, D.E., Hinton, G., Williams, R., 1986. Learning internal representations by error propagation. In: Rumelhart, D.E., Mcclelland, J.L. (Eds.), Parallel Distributed Processing: Explorations in the Microstructures of Cognition. MIT Press, Cambridge, pp. 318–362.

Sánchez-Cuervo, A.M., Aide, T.M., Clark, M.L., Etter, A., 2012. Land cover change in Colombia: surprising forest recovery trends between 2001 and 2010. PLoS One 7, http://dx.doi.org/10.1371/journal.pone.0043943.

SAA/CATI/IEA (Secretaria de Agricultura e Abastecimento/Coordenadoria de Assistência Técnica Integral/Instituto de Economia Agrícola), 1996. Levantamento Censitário de Unidades de Produção Agrícola do Estado de São Paulo – LUPA 1995/96. SSA/CATI/IEA, São Paulo. Accessed February 2016 at: http://www.cati.sp.gov.br/projetolupa/dadosmunicipais9596.php.

SAA/CATI/IEA (Secretaria de Agricultura e Abastecimento/Coordenadoria de Assistência Técnica Integral/Instituto de Economia Agrícola), 2008. Levantamento Censitário de Unidades de Produção Agrícola do Estado de São Paulo — LUPA 2007/08. SSA/CATI/IEA, São Paulo. Accessed February 2016 at: http://www.cati.sp.gov.br/projetolupa/dadosestado.php.

Silva, R.F.B., Batistella, M., Moran, E.F., Lu, D., 2016. Land changes fostering Atlantic forest transition in Brazil: evidences from the Paraíba Valley. Prof. Geogr., http://dx.doi.org/10.1080/00330124.2016.1178151.

Silva, R.F.B., 2015. Florestas Plantadas e Mata Atlântica: análise do uso e cobertura da terra e sua conexões ambientais, políticas e socioeconômicas. (Tese de Doutorado). UNICAMP/IFCH, Campinas, Available at: http://www.bibliotecadigital.unicamp.br/document/?code=000957883&opt=3.

Silvestre, D., Rodriguez, M.E., 2007. Eucalipto/Aracruz Celulose e violações de direitos humanos. Editora PAD, Rio de Janeiro.

Teixeira, A.M.G., Soares-Filho, B.S., Freitas, S.R., Metzger, J.P., 2009. Modeling landscape dynamics in an Atlantic Rainforest region: implications for conservation. For. Ecol. Manage. 257, 1219–1230, http://dx.doi.org/10.1016/j.foreco.2008.10.011.

Vaca, R.A., Golicher, D.J., Cayuela, L., Hewson, J., Steininger, M., 2012. Evidence of incipient forest transition in Southern Mexico. PLoS One 7, http://dx.doi.org/10.1371/journal.pone.0042309.

Vieira, E.T., Santos, M.J., 2012. Industrialização e desenvolvimento regional: política do CODIVAP no Vale do Paraíba na década de 1970. Desenvolvimento Regional em debate 2, 161–181, Available at: http://www.periodicos.unc.br/index.php/drd/article/view/265.

Vieira, E.T., 2009. Industrialização e política de desenvolvimento regional: o Vale do Paraíba na segunda metade do século XX. (Tese de Doutorado). USP/FFLCH, São Paulo, Available at: <http://www.teses.usp.br/teses/disponiveis/8/8137/tde-03022010-143611/pt-br.php>.

Zuquim, M.L., 2007. Os caminhos do rural: uma questão agrária e ambiental. SENAC, São Paulo.