Data Integration for Leaf Area Index Prediction in Function of Land Cover Change

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Abstract. In this study we integrate the use of GIS, remote sensing and ground measurement of LAI (Leaf Area Index) with the instrument LAI-2000 *Plant Canopy Analyzer*, in the *Rio Cachoeira* catchment, in the Sud-Est of Bahia, Brazil. The aim of the work is to show how a very important parameter for monitoring vegetation status, such LAI, can be predicted by simulating land cover changes with Markov chain and cellular automata models.

1 Introduction

In these last years the importance of vegetation in determining and controlling the biogeochemical cycles and the biodiversity state of the biosphere was fully recognized. Today in the circles of environmental management it is well accepted that vegetation loss is affecting negatively the climate, biodiversity, water circulation and the recharge of groundwater reservoirs from local to global level, so the study of vegetation is considered an urgent task. An important aspect that has to be considered in the field of sustainable development is the capacity of vegetation to preserve the ecosystem functions with an efficient primary production. Among the many parameters that describe structurally and functionally the vegetation for quantifying the energy and mass exchange characteristics of a terrestrial ecosystem, the leaf area index (LAI) is one of the most used [1], [2], [3], [4]. LAI is defined as is the projected leaf area per unit ground area (m^2/m^2); it is a quantitative measure of foliage density useful for monitoring vegetation status [5]. LAI is related to the exchange of carbon, oxygen and water with atmosphere, so it would be a very important parameter in modelling biogeochemical cycles [6], [7], canopy photosynthesis and evapotranspiration. LAI can be measured in the field in specific land cover types and then the data can be extended to a territory when cartographic maps of land cover are available. Today thanks to geographic information system (GIS) and remote sensing (RS) technology [8] the production of relatively accurate LAI maps over large areas can be easily achieved [9].

This paper presents an example of how a LAI map can be produced and in what way a LAI map can be predicted in function of land cover change. The example uses a pilot study area selected within an INCO2 project (ECOMAN: *Decision Support System for Sustainable ECOsystem MANagement in Atlantic Rain Forest Rural*

Areas), that has the aim to develop spatial decision support system for sustainable development in tropical forest areas.

2 Study Area

The pilot study area includes the *Rio Cachoeira* catchment, a 4600 km² river basin situated in the region known as "*Cocoa region*", in the Sud-Est of Bahia, Brazil (Fig.1).

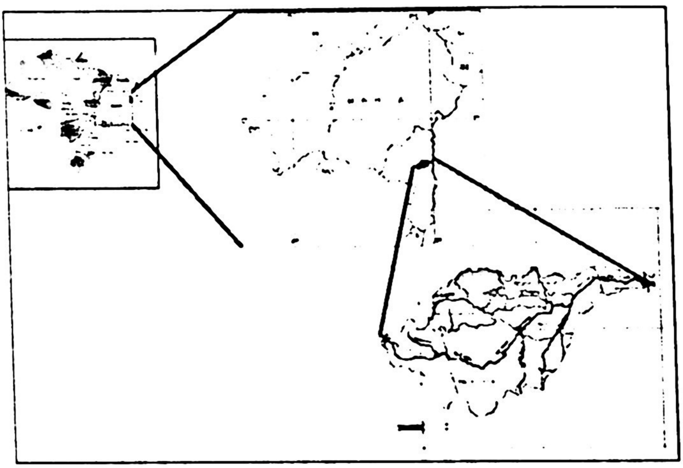

Fig. 1. Study area: *Rio Cachoeira* catchment, Sud-Est of Bahia, Brazil

In this area the problem was to evaluate the possibility of reconstructing the cocoa plantation after the disease of *Vassoura-de-bruxa* (Witch's broom) caused by fungus *Crinipellis perniciosa* since 1989 and to preserve as much as possible the Atlantic forest (*Mata Atlantica*). The past cocoa cultivation in the forest (called *Cabruca*), was assuring a good income and at the same time, the conservation of big fragments of primary tropical forests giving origin to a special ecosystem called *ecossistema cacaueiro* [10]. In fact the percentage of remaining native Atlantic Forest in Bahia is one of the highest of Brazil (about 16%) with the lowest rate of deforestation.

According of a previous study [11] the vegetation of the area is given by 4 main types: native tropical forest (*Mata Atlantica*), Cocoa plantations (*Cabruca*), various phases of natural regeneration (*Capoeira*) and pastures.

3 Data and Methods

The leaf area prediction is based on land cover change. The measurement of LAI have been done in the vegetation types that constitute the main land cover classes. To model land cover change the GIS technology has been used with remote sensing data.

3.1 LAI Measurement

The measures of LAI have been done in June 2003 with LAI-2000 *Plant Canopy Analyser* [12]. The instrument is a radiometer that measures the gap fraction of the canopy in five zenith angles, ranging from 0° to 75°. The measured gap fraction data are inverted to obtain the effective LAI under the assumption of a random spatial distribution of leaves. It is important to underline that LAI measures are affected by all object above ground such as trunks and branches. However, the instrument has the advantage of hemispherical exposure, providing a good angular coverage so the canopy can be estimated with a good approximation. Measures have been done in 10 points along 16 transects of 50 m randomly selected. For each transect the instrument gives the average value and the standard error of the 10 measures.

3.2 Land Cover Classification, Land Cover Change and LAI Prediction

The land cover classification of the study area has been obtained by processing different satellite images by "supervised classification", using the classical Maximum Likelihood" algorithm.

One Landsat 5 TM image (path/row: 216/70: 22/08/1988) was used to work out Land cover map of 1988, while two Landsat 7 ETM+ images (path/row: 216/070; 12/04/2001 and path/row: 216/070: 17/05/2002) were necessary for the Land cover map of 2001 to eliminate the effects of clouds.

In order to predict the land cover changes we used a particular Idrisi software module called "CA_MARKOV" [13]. This application permits the setting of rules for modelling the changes with Cellular Automata (CA) through the Multi-Criteria Evaluation (MCE). The set of rules that define the transition of each pixel from one land cover class to another one are given by the suitability maps of each vegetation type. In our case study the criteria for establishing the suitability maps were slope gradient and terrain elevation and proximities to urban areas and roads and rivers. In Fig. 2 an example of suitability map for Mata Atlantica obtained with the module MCE [14], [15] is given.

The Markov chain model was applied to predict the land cover map of 2011 on the basis of land cover maps of 1988 and 2001. The model is valid only if the land management practice remains constant during the time.

The average LAI for each vegetation type has been superimposed to the maps of 2001 and on the predicted land cover map of 2011. The changes in land cover map are therefore defining the changes in LAI all over the considered landscape.

Fig. 2. Suitability map of "*Mata Atlantica*" (0 – no suitability; 255 – max suitability)

4 Results and Conclusions

The results of LAI measurements in the vegetation types are given in Table1.

Table 1. Mean value of LAI measurements for the vegetation types

Vegetation type	Mean LAI
Cabruca	2.73 ± 0.35
Mata Atlantica	5.37 ± 0.13
Capoeira	2.17 ± 0.57
Pasture	1.57 ± 0.45

As we can see the measures are not far form those reported in literature, notwithstanding according to Asner et Al. [16] not many of the reports of LAI provide clear definition of the methods applied for defining it. Furthermore Xavier and Vettorazzi [17] stress the fact that LAI calculated with LAI 2000 can be underestimated.

The transition matrices between land cover classes is presented in Table 2. The LAI maps of 2001 and 2011 are respectively in Fig 3 and Fig 4.

Table 2. Transition matrices between land cover: 1988-2001 and 2001-2011

	capoeira 2001	cocoa 2001	mata 2001	pasture 2001	urban 2001	water 2001	tot
capoeira 2011	30608.37	2804.04	454.68	30248.46	0	0	64115.55
cocoa 2011	4494.24	57919.68	2537.82	7953.66	0	0	72905.4
mata 2011	2409.93	6527.79	24256.17	1718.64	0	0	34912.53
pasture 2011	3521.88	122.94	2206.08	236355.66	0	0	242206.6
urban 2011	54.09	1.89	35.19	708.48	1782.18	0	2581.83
water 2011	0	0	0	0	0	1090.08	1090.08
tot	41088.51	67376.34	29489.94	276984.9	1782.18	1090.08	417812

	capoeira 1988	cocoa 1988	mata 1988	pasture 1988	Urban 1988	water 1988	tot
capoeira 2001	9580.05	7956.99	3785.85	19756.89	8.73	0	41088.51
cocoa 2001	11223.63	39866.13	5733.09	10549.8	3.69	0	67376.34
mata 2001	6453.9	9837.54	7950.69	5244.75	3.06	0	29489.94
pasture 2001	18533.61	10102.14	8873.37	239269.86	205.92	0	276984.9
urban 2001	87.57	18.36	25.83	686.16	964.26	0	1782.18
water 2001	0	0	0	0	0	1090.08	1090.08
tot	45878.76	67781.16	26368.83	275507.46	1185.66	1090.08	417812

Fig. 3. LAI map of 2001

Fig. 4. Simulated LAI map of 2011

Table 3 gives the hectares of LAI for each land cover class and the changes of total LAI for each land cover class and for the total area.

Table 3. Hectares of LAI for each land cover class and change of total LAI.

LAI (ha)	Pasture	Capoeira	Cocoa	Mata Atlantica
2001	468104.5	89162.1	183937.4	158360.9
2011	409329.1	139130.7	199031.7	187480.3
changes	- 58775.4	+ 49968.6	+ 15094.3	+ 29119.4

According to the model the total LAI of the catchment will increase owing to the increasing of the area covered by *Capoeira*, Cocoa and *Mata Atlantica*.

From this exercise it is clear that if the scenario of land cover change follows the tendency of the two considered periods, the LAI will increase in the catchment with benefits for the total ecosystem.

In conclusion the GIS technology being able to integrate remote sensing and ground data collection can be very useful to simulate scenarios for predicting very important parameters such as Leaf area index (LAI).

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