Anais VIII Simpósio Brasileiro de Sensoriamento Remoto, Salvador, Brasil, 14-19 abril 1996, INPE, p. 533-539.

LAND COVER MAPPING AND CARBON POOLS ESTIMATES IN RONDONIA/BRAZIL

JENER F. L. MORAES[1]; FREDERIQUE SEYLER[2] ; CARLOS C. CERRI[2]; BORIS VOLKOFF[3]

[1]IAC-Instituto Agronômico de Campinas, C.P. 28, 13020-470, Campinas, Sp, Brazil
[2]CENA-Centro de Energia Nuclear na Agricultura, C.P. 96, 13400-970 Piracicaba, SP, Brazil
[3]ORSTOM, 70-74, route d Aulnay, 93140 Bondy, France

Abstract: In order to estimate changes in carbon pools and fluxes to the atmosphere, we used LANDSAT/TM data to calculate the extent of areas converted to pasture to different lengths of time in a 100 x 92 km area of the southwestern Brazilian Amazon. Image processing and the supervised classification allowed the production of an accurate land cover map including forest and pastures of different ages. The results showed that almost 30% of the natural forest were deforested and occupied with pasture. From the 2800 km^2 of pasture almost 60% consists of pasture with less than three years of establishment. Estimates of carbon pools and fluxes to the atmosphere were carried out using the results of LANDSAT image analysis and published data about carbon stocks in vegetation and soil. The results showed that a large amount of carbon (12×10^3 g C m^{-2}) is released after three years under pasture. From the initial burning and after fifth year under pasture, the system functioned as a source of CO_2 to atmosphere. After this period the balance is slightly negative and the amount of CO_2 released is lower than the amount released in the initial period.

Keywords: Land-use, Remote Sensing, Carbon Pools, Amazon Basin

1. Introduction

Forested areas, especially those in the tropics are undergoing rapid changes as the result of human influences. In the Brazilian Amazon, occupation was facilitated by governmental programs of colonization and exploitation over the past two decades (Brooner 1989).

Tropical forests are exploited for a variety of purposes, including timber extraction, shifting cultivation, permanent agriculture and pasture. Estimates of the area of pasture in the Brazilian Amazon range from 70,000 km^2 (Serrão and Toledo 1990), 100,000 km^2 (Hecht 1985) and 120,000 km^2 (Koehelhepp 1984).

The large scale conversion of forest to pasture leads to changes in carbon storage in forest biomass and soil (Fearnside *et al*. 1993,, Kauffman *et al.* submitted, Moraes *et al*. in press), and therefore, the global carbon budget. In the decade-to-century time frame, soil carbon and plant biomass are the pools most likely to either buffer or amplify atmospheric carbon accumulation (Skole *et al*. 1994).

In order to calculate changes in carbon pools and fluxes in forest-converted-to pastures areas we must (i) obtain precise estimates of pastures areas; (ii) quantify the carbon pools in different compartments and (iii) the respectives rates of soil organic matter decomposition on different time scales.

Recent studies have confirmed the capability of satellite remote sensing to measure deforestation in the Brazilian Amazon and categorize different types of land-use, including large pastures, small farms, extraction activity and mining (Botkin *et al*. 1984, Skole *et al.* 1994).

To quantify the carbon pools in different compartments, we dispose of (i) some improved estimates of total aboveground biomass (Klinge and Rodrigues 1974, Brown and Lugo 1992, Fearnside 1993, Kauffman *et al.* submited), (ii) the soil carbon stocks in Amazonian forest and (iii) its changes due to land exploitation (Volkoff and Cerri 1987, Cerri *et al.* 1991, Veldkamp 1994, Moraes *et al*. 1995 and Moraes *et al.* in press).

In the first part of this paper we focus on the mapping of the land cover in a twenty thousand hectare area of southwestern Rondônia using Landsat/TM images. This land-cover classification was then extrapolated to an area of 100 x 92km. In the second part this estimates of deforested areas converted to pasture are joined with published data about carbon stocks in soil and vegetation in order to understand the carbon balance and its dynamics within this area.

2. Material and methods

2.1 Study area

The study area was located in the southwestern Brazilian Amazon basin, in Rondonia State. The experimental site was located at Nova Vida Ranch (10^o 10´ 05” S, 62^o 49´ 27” W;), between the cities of Ariquemes and Jaru. Pastures are dominated by

Brachiaria brizantha sewed in the years 1989, 1987, 1972 and 1911 and Panicum maximum sewed in the years 1983, 1972 and 1979.

2.2 Remote sensing data

One quadrant of digital Landsat thematic mapper (TM) image (Path: 231C, Row 67) was acquired on 7 July 1991, at the peak of the dry season.TM scene comprised image data in three wavelength bands in the visible (TM1 0.76-0.90 μm; TM2 0.53-0.61 μm and TM3 0.62-0.69 μm), and three in the reflected infrared (TM4 0.76-0.90 μm; TM5 1.55-1.75 and TM7 2.08-2.35 μm) .

2.3. Digital Image Processing

Image processing was performed using the PLANETES® (ORSTOM) software. The techniques of image enhancement consisted of linear contrast modifications, image filtering operations and band ratio. A principal component analysis was performed on the three visible and three infrared bands from the TM data. Considering the characteristics of the vegetation cover in the study area that presents pasture in different stages of development, we have calculated the normalized vegetation index, using the following band ratio:

$$IVN = 128.[1+(TM4 - TM3)/(TM4 + TM3)]$$

2.4. Image Classification

Using a color composition (5R4G3B), training areas were sampled. These areas include forest, pastures of different ages, rural residential (urban areas and non-vegetated surfaces) and water. More than one training area was selected for each land cover class. Classes with small extent were characterized by few training area while classes with large extent have more training areas. All sampled pixels were localized inside the perimeter of the studied ranch where ground information collected during 1992 was available. Maximum, minimum, average and standard deviation of the digital number (DN) were calculated for each land cover class with the purpose of developing a representative set of spectral signature for the land cover classes. The supervised classification method applied was based on the Euclidean minimum distance between a pixel and the mean of the training cluster (Wilkinson 1991). The channels used for the classification were the middle infrared (TM5), the vegetation index and the first principal component. These channels offered the best discrimination between the differents land-cover classes and provided a good discrimination between pastures of different ages. To evaluate the performance of the classification, a confusion matrix was made by comparing the classification results with the reference data (Gong and Howarth 1992). The reference data was generated based on sample identification (ground information).

2.5. Estimates of Carbon Pools

The calculation of a C balance of terrestrial ecosystem requires the knowledge of the carbon stored in the different compartments and its dynamic (or fluxes) between the terrestrial ecosystem and the atmosphere. A review of the literature provided the information needed about the different variables used to calculate the carbon balance in forest converted to pasture area.

Above-ground biomass: Estimates of the biomass of Amazon rain forest in Rondônia , reported values of 290.2 t ha^{-1} and 361.2 t ha^{-1} (Kauffman et al., submitted). In the study of biomass estimation at Nova Vida ranch, Graça (personal communication) found an above-ground biomass of 298.7 t ha^{-1}. For the present research, a mean value of 316.7 t ha^{-1} calculated with the above values was used. For the corresponding carbon content of biomass, we utilized the value of 0.50 used in calculations by Brown and Lugo (1984) and Fearnside *et al*. (1993) which resulted in a carbon content of 158 t C ha^{-1}.

Burning Coeficient (CE): Kauffman *et al.* (submitted) estimated a burning coeficient of 42% and 57% in Rondônia. Measurements of biomass and combustion efficiency at Nova Vida ranch carried out by Graça (personal communication) reported a combustion efficiency (CE) of 39.5%. A mean value of 46% was used in this study.

Below-ground biomass: Fearnside et al. (1993) estimated that below-ground biomass represented 15.1% of the total biomass. Considering an above-ground biomass of 316.7 t ha^{-1}, we estimated a below-ground biomass of 56.3 t ha^{-1} which represents approximately 28 t C ha^{-1}.

Decay of unburnt biomass: The biomass remained after the initial burn is consisted of trunks that presents a CE of 20.9% (Fearnside *et al.*, 1993). We assumed this value to determined the decay of the remained biomass.during subsequent burns.

Pasture growth: For pasture biomass we assumed a mean value of 6.4 t ha^{-1} yr^{-1} considering the estimates of Teixeira (1987) and Barbosa (1994).

Soil Carbon: A total of 3.70±0.11 kg C m^{-2} was found in the top 30 cm of forest soil (Moraes *et al*., in press). The loss of carbon derived from forest was estimated on 0.50, 0.30 and 0.70 kg C m^{-2} respectively between zero to three, three to five and five to twenty years. The net increment of carbon introduced by pasture in the 0-30cm layer was 0.70 kg C m^{-2} in the first three years of pasture, 0.40 kg C m^{-2} between three to five years and 1.20 kg C m^{-2} between five to twenty years of pasture establishment.

3. Results and discussion

3.1. Visual and Spectral Analysis

The interpretation of the RGB colored composite image (5R4G3B) based on ground information permitted the discrimination of eight different land-cover classes listed in Table 1. With the exception of the class "Rural residential" (houses and bare soils), the different classes can not be distinguished on the visible channels (1, 2 and 3) (Figure 1). The TM bands 4, 5 and the calculated images VI (Vegetation Index) and PC1 (First Principal Component) showed better discrimination between the different and cover classes. Comparing the electromagnetic reflectance (EMR) of the three classes of pasture, we observed a decrease from younger to older pastures in the near infrared and an increase in the middle-infrared. In older pasture, a reduction of vigor and water content in the dry season which characterizes a pattern of senescence, resulted in a lower reflectance in near infrared. This effect is confirmed in the middle infrared, where the lower the water content of a plant, the higher its reflectance (Belward 1991). According to Knipling (1967), the probable cause of decreased reflectance in near infrared is the internal changes in plant tissues, forming a series of horizontal layers of cell walls resulting in a reduction of the air space.

In the first PC image, the differences between the different land cover classes are enhanced , providing a better discrimination for image classification (Figure 1).

Table1.Land-cover classes observed in the Landsat TM image of 100x92 km.

Land-cover-classes	Área (km^2)
Forest	6370
Pasture with more than 5 year old	752
Pasture between 3 to 5 year old	410
Pasture with less than 3 year old	1613
Rural residential	16
Water	2
Roads	6
Not classified	50

3.2. Image Classification

The land cover types in the study area are mostly forest and pastures at different stages of development. Table 1 shows the eight classes of land-cover with the pastures divided in three sub-groups, according to their age. The area of each class was obtained from the classified image.The area occupied by the less than three years old pasture is twice the extent of the more than five years old pasture. Our observations are consistent with the peak deforestation which occurred in 1987 (Fearnside 1992, Moran 1993).

The ground data, collected one year after the satellite acquisition, showed that in the area that surrounded the Nova Vida ranch, areas of secondary regrowth following pasture abandonedment were not found. Therefore, the uncertainty often reported in the literature, related to the similar image response of new pastures and abandoned ones were not a major problem during this study.

The percentage of not classified pixels (0.5%) was very low suggesting some assumptions: **(i)** the channels that provided the best spectral discrimination between land cover classes were correctly choosen; **(ii)** the small size of the training area reduced misclassification; **(iii)** the algorithm used in the supervised classification was well adopted.

3.3. The Carbon Balance: (gains and looses)

In the present paper we assumed that all deforested land was converted to pasture and remained as pasture for at least twenty years. The definition of this period was based on the presence in the study area of many pastures with twenty or more years old.

In Table 2 we show the initial carbon pool (in forest) and its fluxes to the atmosphere after burning and pasture establishment. First the results were expressed in terms of the gain or loss of carbon per square meter. Then we calculated the balance for an area of 100 x 92 km, using the surface of forest and pasture of different ages obtained from Landsat TM image analysis reported in Table 1.

The highest release of CO_2 to the atmosphere (12 x 10^3 g C m^{-2}) occurred in the first three years after burning. Forest biomass burning (7.3 x 10^3 g C m^{-2}) and subsequent decay of the unburnt biomass (4.7 x 10^3 g C m^{-2}) are the main contributors to the total amount of CO_2 released during this period. After the initial burning, more than fifty percent of the total carbon of the forest biomass remained as unburnt biomass. The decay of this unburnt biomass occurs over a period of ten to twenty years (Fearnside 1992, Barbosa 1994), as a result of natural decomposition or due to subsequent reburnings of the pasture . The total amount of carbon released after twenty years was 16 x 10^3 g C m^{-2}.

In the first five years after forest burning, the system functions as a source of C-CO_2 to the atmosphere. Between five to twenty years the amount of carbon released to the atmosphere is far lower and the system tends towards equilibrium. After about twenty years, the system which was functioning as a source of atmospheric CO_2 tends to function as a sink. The reduction of the amount of CO_2 released to the atmosphere in the final period is mainly related to the extinction of the unburnt biomass and the increase of C sequester by grass during the photosynthesis. Part of the C-CO_2 converted to biomass is accumulated in the soil (Fisher *et al.,* 1994).

Using (i) the net fluxes of carbon presented in Table 2 and (ii) the areas of pasture of different age within the region (100 x 92 km, see table 1), we estimated the amount of carbon storage in the remaining forest and the loss of carbon for different periods of time. The amount of carbon stored in the 6400 km^2 of forest corresponds to 0.14Pg (1 Pg = 10^{15} g). After twenty years the total amount of carbon released is 0.023 Pg. Of this total 0.02Pg was released during the first three years after forest burning. Making the assumption that twenty percent of the remaining forest was converted to pasture (the maximum authorized deforestation is 50% of the total area), the amount of carbon released to the atmosphere after twenty years would be 0.05 Pg of C.

Estimates of deforested area in the entire Brazilian Amazon basin is reported at almost 10.5% (426000 km^2) of total forest area (Fearnside 1993). If fifty percent where used for pasture for at least twenty years, the amount of CO_2 released to the atmosphere would be 3.4×10^{15} g C which is far lower than the total of CO_2 release due to fossil fuel combustion (5.6×10^{15} g C yr^{-1}), Houghton (1990). In relation to the total amount of atmospheric carbon (353 ppmv CO_2, i. e. 748×10^{15} g C (Lal 1993)), the contribution from Amazon forest burning represents less than 0.46 % (1.6 ppmvCO_2).

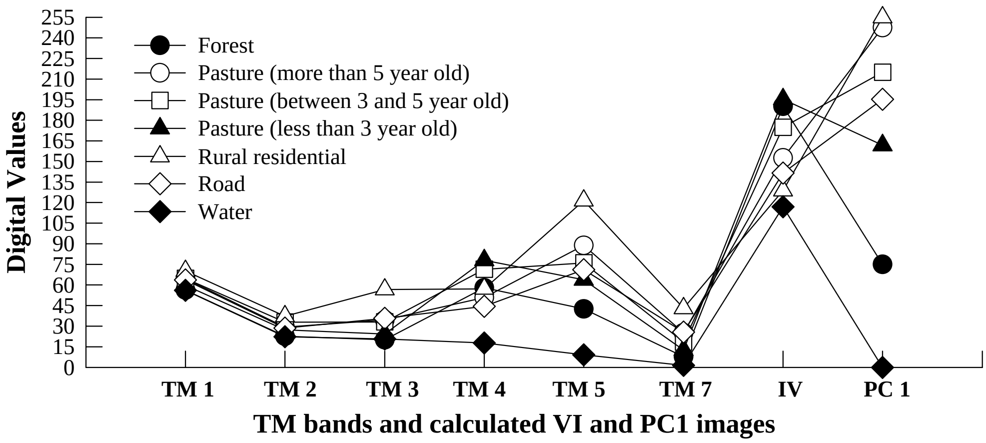

Figure 1. Spectral signature of land cover classes based on Landsat/TM scene and field stuty

4. Conclusions

This research considered the performance of LANDSAT/TM data for mapping areas of natural forest and pastures of different ages in the Brazilian Amazon. The results showed that the accuracy of digital image classification is closely related to factors such as the date of image acquisition, the definition of those channels which provide the best discrimination between different land covers and the size of the training samples areas**.** During dry season differences in electromagnetic reflectance were more intense between pastures with differents ages. Near and middle infrared bands, vegetation index and first principal component images provided better discrimination of land cover classes. The results confirmed the capability of Landsat data for estimating areas converted to pasture and its ability to contribute with important data about the carbon balance in the Amazon region. A limitation of the methodology seems to be the difficulty in discriminating between those areas of recent pasture implantation, abandoned pasture and secondary regrowth.One important research priority is the refinement of this methodology to provide the best discrimination between the before mentioned land cover classes.

Table 2. Carbon pools (gain and loss) associated to pasture establishment in Rondônia.
(minus represents the amount of carbon release to the atmosphere)

Compartments	Carbon pools	C - Transfer			
	x 10^3 g C m^{-2}				
		0-3years	**3-5years**	**5-20years**	**End of 20 years**
Forest Biomass					
Forest above-ground biomass	15.8				
Forest bellow-ground biomass	2.8	-1.4	-1.4		-2.8
Forest burning		-7.3			-7.3
Decay of unburnt biomass		-4.7	-2.4	-1.4	-8.5
Soil Carbon					
Total soil carbon	3.7				
Decay of carbon from forest		-0.5	-0.3	-0.7	-1.5
Carbon introduced by pasture		0.7	0.4	1.2	2.3
Pasture Biomass					
Above-ground-biomass		0.6			
Bellow-ground-biomass		1.0			
Total	22	-12	-4	-1	-16

When large areas of natural forest are converted to pasture the system functions as a net source of CO_2 to atmosphere during the first five years. Although the amount of CO_2 released over the next twenty years is far lower than the amount released from fossil fuel combustion per year.

Continued refinement of techniques to monitor soil carbon pools and the rates of deforestation using remote sensing will be necessary to provide the best estimation of the carbon balance between terrestrial vegetation and the atmosphere.

5. References

Barbosa, R. I., 1994, Efeito estufa na Amazônia: Estimativa da biomassa e a quantifica‡ão do estoque e libera‡ão de carbono na queima de pastagens convertidas de florestas tropicais em Roraima, Brasil. (University of Amazonas: Master Science, Amazônia, Brasil), 100p.

Belward, A. S., 1991, Spectral characteristics of vegetation, soil and water in the visible, near-infrared and middle-infrared wavelengths. In *Remote Sensing and Geographical Information Systems for Resource Management in Developing Countries*, edited by A.S. Belward and C. R. Valenzuela (Netherlands), pp.31-53.

Botkin D. B., Estes, J. E., Macdonald, R. M. and Wilson, M. V., 1984, Studying the earth's vegetation from space. *Bioscience*, **34**, 508-514.

Bronner W.G., 1989, The application of remote sensing in South America: Perspectives for the Future Based on Recent Experiences. In *Change the Global Environment: Perspectives on Human Involvement*, edited by D. B. Botkin, M. F. Gaswell, J. E., Estes and A. A. Orio (New York: Academic Press; New York: Harcourt Brace Jovanovich, Publishers), pp. 215-230.

Brown, S., Gillespie, A. J. R., Lugo, A. E., 1989, Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*, **35**, 881-902.

Brown, S., and Lugo, A. E., 1990, Tropical secondary forests. *Jounal of Tropical Ecology*, **6**, 1-32.

Brown, S., and Lugo, A. E., 1992, Above-ground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia*, **17**, 8-18.

Brown, S., and Lugo, A. E., 1984, Biomass of tropical forests: A new estimate based on forest volumes, *Science*, **223**, 1290-1293.

Buschbacher, R. J., 1986, Tropical deforestation and pasture development. *Bioscience*, **36**, 22-28.

Cerri, C. C., Feller, C., and Chauvel, A., 1991, Evolução das principais propriedades de um latossolo vermelho escuro após desmatamento e cultivo por doze e cinquenta anos com cana-de-açúcar. *Cahiers ORSTOM Série Pédologie*, **26**, 37-50.

Fearnside, P. M., Leal Jr, N. and Fernandes, F. M., l993, Rainforest burning and the global carbon budget biomass, combustion efficiency, and charcoal formation in the Brazilian Amazon. *Journal of Geophysical Research*, **98,**16-733,16-743.

Fearnside, P. M., Graça, P. M. L. de A., Leal, N., Rodrigues, F. J. A., and Robinson, J. M., Tropical forest burning in brazilian Amazonia: measurements of biomass, combustion efficiency and charcoal formation at Altamira, Pará. (in preparation).

Fearnside, P.M., 1992. Greenhouse gas emissions from deforestation in the Brazilian Amazon. In *Carbon Emissions and Sequestration in Forests: Case Studies from Sevem Developing Countries*, edited by W. Makundi and J. Sathaye (Washington: U.S. Department of Energy; Washington DC), pp. 1-73.

Fisher, M.J., Rao, I. M., Ayarza, A., Lascano, C.E., Sanz, J. I., Thomas, R.J. and Vera, R.R., 1994, Carbon storage by introduced deep-rooted grasses in the South American savannas. *Nature*, **371**, 236-238.

Gong, P. and Howarth, P.J., 1992, Frequency-based contextual classification and gray-level vector reduction for land-use identification. *Photogrammetry Engineering* & *Remote Sensing*, **58**, 423-437.

Hecht, S., 1985, Environment, development and politics: Capital accumulation and the livestock sector in eastern Amazonia. *World Development*, **13**, 663-684.

Houghton, R.A., 1990, The global effects of tropical deforestation. *Environmental Science and Technology*. **24**,414-422.

Kauffman, J. B., Cummings, D. L., Ward, D. E., and Babbit, R., 1995, Fire in the Brazilian Amazon: biomass, nutrient pools, and looses in slashed primary forests. (submitted to Oecologia).

Klinge, H., and Rodrigues, W. A., 1974, Phytomass estimation in a Central Amazon rain forest. In *IUFRO Biomass Studies*, edited by H. E. Young (Maine, Univ. Press), pp. 339-350.

Klinge, H., Rodrigues, W. A., Bruning, E., and Fittkau, E. J., 1975, Biomass and structure in a central Amazon rain forest. In *Tropical ecology systems: Trends in terrestrial and aquatic research*, edited by Golley F. B. & Medina, E. (Nova York, Springer-Verlag,), pp. 115-122.

Knipling, E. B., 1967, Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sensing of Environment*, **1**, 155-159.

Koehelhepp, G., 1984, Development planning and practices of economic exploitation in Amazonia. Recent trends in spatial organization of tropical frontier region in Brazil (1966-1981). In *The Amazon, limnology and landscape of a mighty tropical river and its basin*, edited by H. Sioli (Netherlands: Dr. W. Junk Publishers), pp. 649-674.

LAL, M., and Chakraborty, B.,1993, Evidence for global warming: Antropogenic factors. In *Global warming: Concern for Tomorrow*, edited by Lal, M.,(Nova Delhi, McGraw-Hill Publis. Comp. Ltd), pp. 19-36.

Moraes, J. F. L., Volkoff, B., Cerri, C. C., and Bernoux, M., 1995, Soil properties under natural forest and changes due to pasture installation in Rondônia/Brazil. (in press, Geoderma).

Moraes, J.F.L., Cerri, C.C., Melillo, J.M., Kocklighter, D., Neill, C., Skole, D. and Steudler, P., 1995, Soil carbon stocks of the Brazilian Amazon basin. *Soil Science Society American Journal*, **59**, 244-247.

Moran, E.F., 1993, Deforestation and land use in the Brazilian Amazon. *Human Ecology*, **2,** 1-21.

Olson, J. S., Watts, J. A., and Allison, L. J., 1983, Carbon in live vegetation of major world ecosystems. U.S. Department of Energy, Washington, DC, TROO4.

Serrão, E.A. and Toledo, J.M., 1990, The search for sustainability in Amazonian pastures. In *Alternatives to deforestation: steps towards sustainable use of the Amazon rain forest*, edited by A.B. Anderson (New York, Columbia University Press), pp. 195-214.

Skole, D. L., Chomentowski, W., Salas, W.A., and Nobre, A.D., 1994, Physical and human dimensions of deforestation in Amazonia. *Bioscience*, **44,** 314-322.

Teixeira L. B., 1987, Dinâmica de ecossistema de pastagem cultivada em rea de floresta na Amazônia central. (University of Amazonas: Master Science, Amazônia, Brasil).

Veldkamp, E., 1994, Organic carbon turnover in three tropical soils under pasture after deforestation. *Soil Science Society American Journal*, **58**,175-180.

Volkoff, B. and Cerri, C.C., 1987, Carbon isotopic fractionation in subtropical Brazilian grassland soils. Comparison with tropical forest soils. *Plant and Soil*, **102**,27-31.

Wilkinson, G. G., 1991, The processing and interpretation of remotely-sensed satellite imagery - A current view. In *Remote Sensing and Geographical Information Systems for Resource Management in Developing Countries*, edited by A.S. Belward and C. R. Valenzuela (Netherlands), pp.31-53

Acknowledgements
This work was supported by FAPESP (proc. 92/0635-4 and 92/0636-8).