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Spatial resolution influence on the identification of land cover classes in the Amazon environment

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ABSTRACT

To evaluate the role played by the spatial resolution in distinguishing land cover classes in the Amazon region, different levels of spatial resolution (60, 100, 120, 200 and 250 meters) were simulated from a Landsat_5 Thematic Mapper (TM) image. Thematic maps were produced by visual interpretation from the original (30×30 meters) and simulated set of images. The map legend included primary forest, old and young woody secondary succession, and non-forest. The results indicated that for the discrimination between primary forest and non-forest, spatial resolution did not have great influence for pixel size equal or lower than 200 meters. The contrary was verified for the identification of old and young woody secondary vegetation due to their occurrence in small polygons. To avoid significant changes in the calculated area of these land cover types, a spatial resolution better than 100 meters is required. This result is an indication that the use of the future Brazilian remote sensing satellite (SSR-1) for secondary succession identification may be unreliable, especially for latitudes between S10^{o} and S15^{o} where critical areas of deforestation are located and pixel size is expected to vary within the same scene from 100 meters (S10^{o}) to 200 meters (S15^{o}).

Key words: spatial resolution, remote sensing, Amazon region, thematic maps, tropical rain forest.

1. INTRODUCTION

Concerns about deforestation estimates in the Amazon region have increased since the first data were published in 1978 from visual interpretation of Landsat Multispectral Scanner (MSS) images by the National Institute for Space Research (INPE – Brazil). The relative success of this first initiative motivated the improvement of the methodology used for deforestation quantification in the Amazon region (INPE 2000). Since 1998, visual interpretation has been performed on the computer screen at 1:100,000 scale using color composite images of the Landsat 5 TM sensor. Alternative procedures, such as the use of images derived from the linear spectral mixture models (Shimabukuro et al. 1999) or from the segmentation technique (Rodriguez-Yi et al. 2000), followed by visual interpretation, have been considered recently. Other computer supervised and/or unsupervised digital classification techniques were used by several researchers to map land cover classes in small portions of the Amazon region (e.g., Nelson and Holben 1986, Irons et al. 1985, Townshend and Justice 1988, Cihlar 2000).

The different procedures used to produce thematic maps can be applied over optical data collected by orbital sensors with distinct spatial res-

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olution. Townshend and Justice (1988) evaluated the influence of the spatial resolution on the global monitoring of land transformations, including landscapes in the Amazon region. They concluded that a sensor with a resolution of 500 meters would be recommended to provide the best compromise between land cover change characterization and the size of the resultant data volume. However, this conclusion was based on a global approach that is different from the regional one used in Brazil, in which clear cutting, secondary succession and selective logging are considered as deforestation categories. The identification of secondary succession stages of vegetation in the Amazon region is an important subject in the studies of the CO_2 atmospheric emission (Schimel et al. 1995, 1996), the ecosystem equilibrium (Mausel et al. 1993, Moran et al. 2000), and of the rain forest ecosystem preservation (Alves and Skole 1996, Alves et al. 1997, McNeill et al. 1994).

A short review on the estimates of tropical forest areas from data with different spatial resolution was presented by Mayaux and Lambin (1995). According to Mayaux and Lambin (1995), deforestation estimates by visual or digital analysis of high spatial resolution data require a good knowledge of the ecology and land use patterns of the area under investigation, which is difficult to achieve at very broad scales. A coarse spatial resolution leads to a loss of spatial detail at a rate that depends on the spatial structure of the landscape, thus affecting the estimate of the land cover area, the validation of results and the assessment of product accuracy. Moody and Woodcock (1994) mentioned the effect of spatial aggregation on the representation of cover-types proportions, which can be significant at broad scales. These effects are due to the necessity of correcting proportional errors, caused by the coarse spatial resolution, to extract quantitative information on forest cover from broad scale maps and to compare such maps with finer scale observations. According to Achard et al. (2001), the legend maps and the statistical data derived from coarse spatial resolution satellite sensors can be misleading without accuracy assessment and a correction procedure.

The objective of this work is to evaluate the influence of the spatial resolution on the identification of land cover classes in the Brazilian Amazon region. For this purpose, different levels of spatial resolution (60, 100, 120, 200 and 250 meters) were simulated from a Landsat 5 Thematic Mapper (TM) image (30 $\times$ 30 meters). The investigation is important for the design of the future Brazilian remote sensing satellite (SSR-1) planned for the near future. The SSR 1 will operate in an equatorial orbit and carry on board three cameras with a large field of view. The cameras will collect images from N5^o to S15^o of latitude with an extremely short revisit time of less than two hours, thus improving the chances of acquiring cloud-free data (Carvalho et al. 1997). Because of the optical design of the camera modules, pixel size should vary within the same scene from 50 meters (nadir), 100 meters (S10^o), to 200 meters (15^{o}S).

2. MATERIALS AND METHODS

The study area is located between the longitudes W66^{o}59' and W67^{o}25' and latitudes S09^{o}53' and S09^{o}57', in the State of Acre, Brazil. The area was selected due to the presence of typical Amazonian land cover types and the existence of previous research activities and resulting ground-based information. The landscape is characterized by the principal road and the secondary ones, locally called "feeder roads", which are perpendicular to the principal road. Along the road network, farmers have developed different types of commercial agriculture and pasture. Abandoned areas are also common and are characterized by different stages of secondary succession of vegetation.

To evaluate the impact of the spatial resolution on the identification of the different land cover classes, a filtering procedure proposed by Banon (1990) was applied to simulate low spatial resolution images (60, 100, 120, 200 and 250 meters) from Landsat 5/TM data (30 $\times$ 30 meters). These simulated spatial resolution values are compatible with variations in pixel size that will be present in a given scene produced by the future SSR 1 cameras, from nadir to extreme viewing. The algorithm is based on the assumption that most of the imagery systems for Earth remote sensing can be represented as linear filters having separable and gaussian Point Spread Functions. The procedure consists in enchaining elementary filters which have a small, finite Point Spread Function support. Details on the method, including equations and examples of applications, can be found in Banon (1990).

The current methodology adopted by INPE to calculate deforestation estimates in the Amazon region is based on the use of a linear mixing model, followed by the segmentation of the shadow fraction image, in which unsupervised digital classification is performed. Refinements of these classification results are made through visual interpretation on the computer screen of color composites (TM3(blue), TM4(red) and TM5(green)). In the study area, the production of the thematic maps from both the original and the simulated images was performed essentially from visual interpretation on computer screen of color composites and from the availability of ground-based information. The legend adopted to produce the maps included the following land cover types: primary forest (preserved tropical rain forest), old and young woody secondary succession vegetation stages (woody biomass that grows after land abandonment), and non-forest (soil, pasture and crops). The area of these land cover types in each of the six thematic maps (original plus five simulated images) was calculated by an algorithm.

The map generated from the original TM/Landsat image (30 × 30 meters) was considered as reference in order to compare the results achieved with the other levels of spatial resolution. This comparison was performed by using the contingency table to calculate the Kappa coefficient of agreement, an index frequently derived to express classification accuracy (Foody 2002). The Kappa coefficient to express the map category accuracy is described by Congalton (1991) through the equation:

$$Kappa_i = \frac{n x_{i+} x_{+i}}{n x_{i+} - x_{i+} x_{+i}}$$

where:

- $Kappa_i$ is the Kappa coefficient for the map category i;
- n is the total number of observations;
- x_{i+} and x_{+i} are the marginal raw and column totals, respectively.

The global mapping accuracy (all map categories together) of each thematic map was based on the equation described by Bishop et al. (1975):

$$Kappa_{total} = \frac{n \sum_{i=1}^{l} x_i - \sum_{i=1}^{l} (x_{i+} x_{+i})}{n^2 - \sum_{i=1}^{l} (x_{i+} x_{+i})}$$

where:

- $Kappa_{total}$ is the Kappa coefficient considering all the map categories;
- n is the total number of observations;
- x_{i+} and x_{+i} are the marginal raw and column totals, respectively;

The significance of the Kappa coefficients was not calculated since these coefficients were determined rather than estimated for the entire study area or for each map category.

3. RESULTS AND DISCUSSION

Figure 1 shows the color composites of the original and simulated Landsat 5/TM images used in the visual interpretation. The images were enhanced by linear contrast stretch. In Figure 1, primary forest and old/young woody secondary vegetation are represented by reddish shades, whereas non-forest surface components (e.g., soil, emerging and green pasture, crops) appear in bluish and yellowish colors.

Figure 2 shows the thematic maps generated from visual interpretation of the images depicted in Figure 1. As observed in Figure 2, the most important changes associated with the spatial resolution degradation, from 30 to 250 meters, are related to

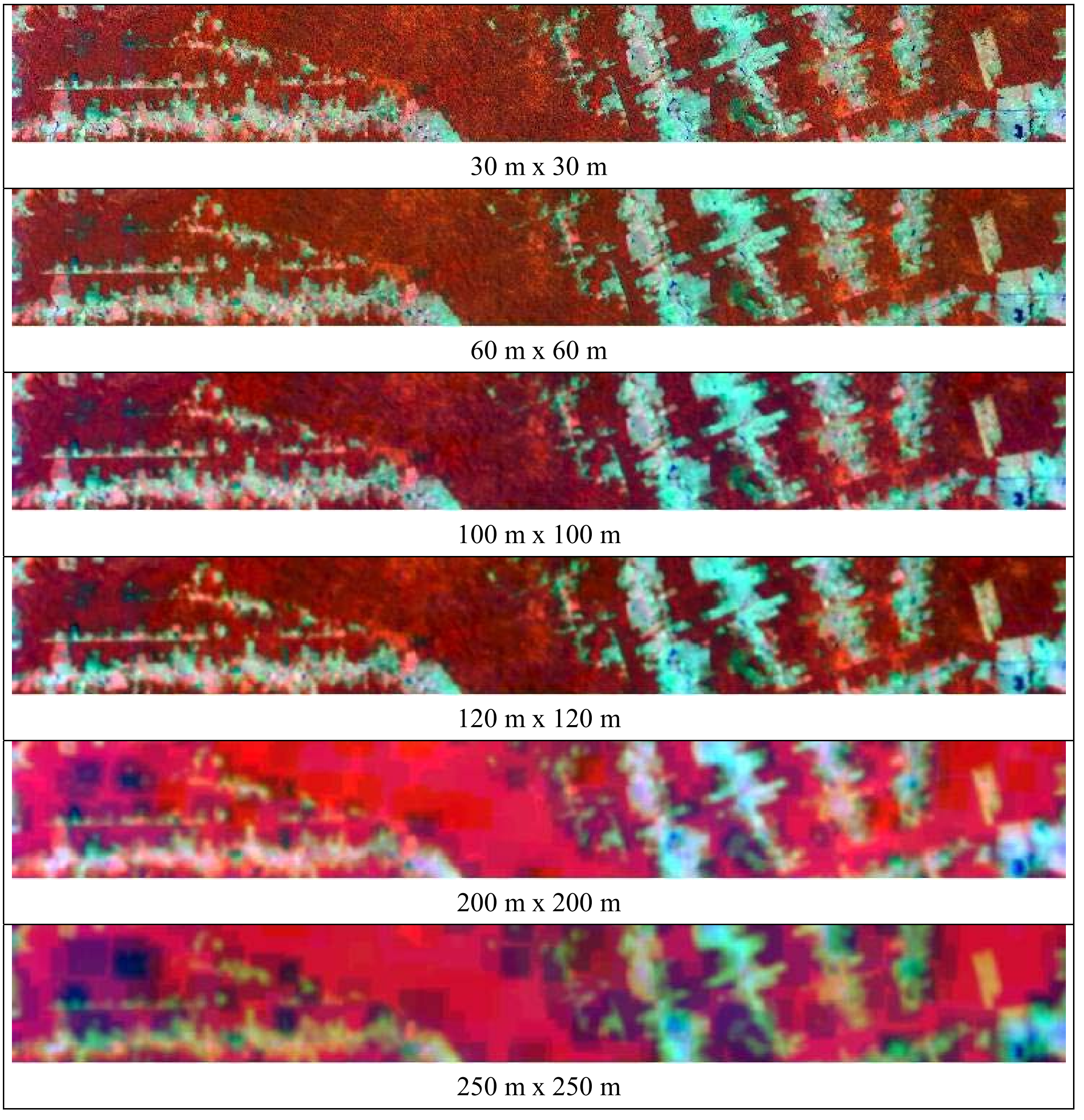


Fig. 1 – Landsat 5/TM images at different simulated levels of spatial resolution. The bands 3, 4 and 5 are depicted in blue, red and green colors, respectively.

the smoothing of polygon boundaries that characterize the transition between forest and other surface components. Furthermore, by coarsening the spatial resolution, small polygons of old and young woody secondary vegetation disappear or are incorporated into the other land cover types.

Figure 3 illustrates changes in area of each land cover type as a function of the spatial resolution. As shown in Figure 3a, estimates of forest and non-forest areas are not significantly affected by changes in spatial resolution up to 200 meters, beyond which an increase in area of forest is observable due to pixel incorporation of other land cover types (e.g., old woody secondary vegetation). On the other hand, estimates of old and young woody secondary vegetation are strongly affected by spatial resolution

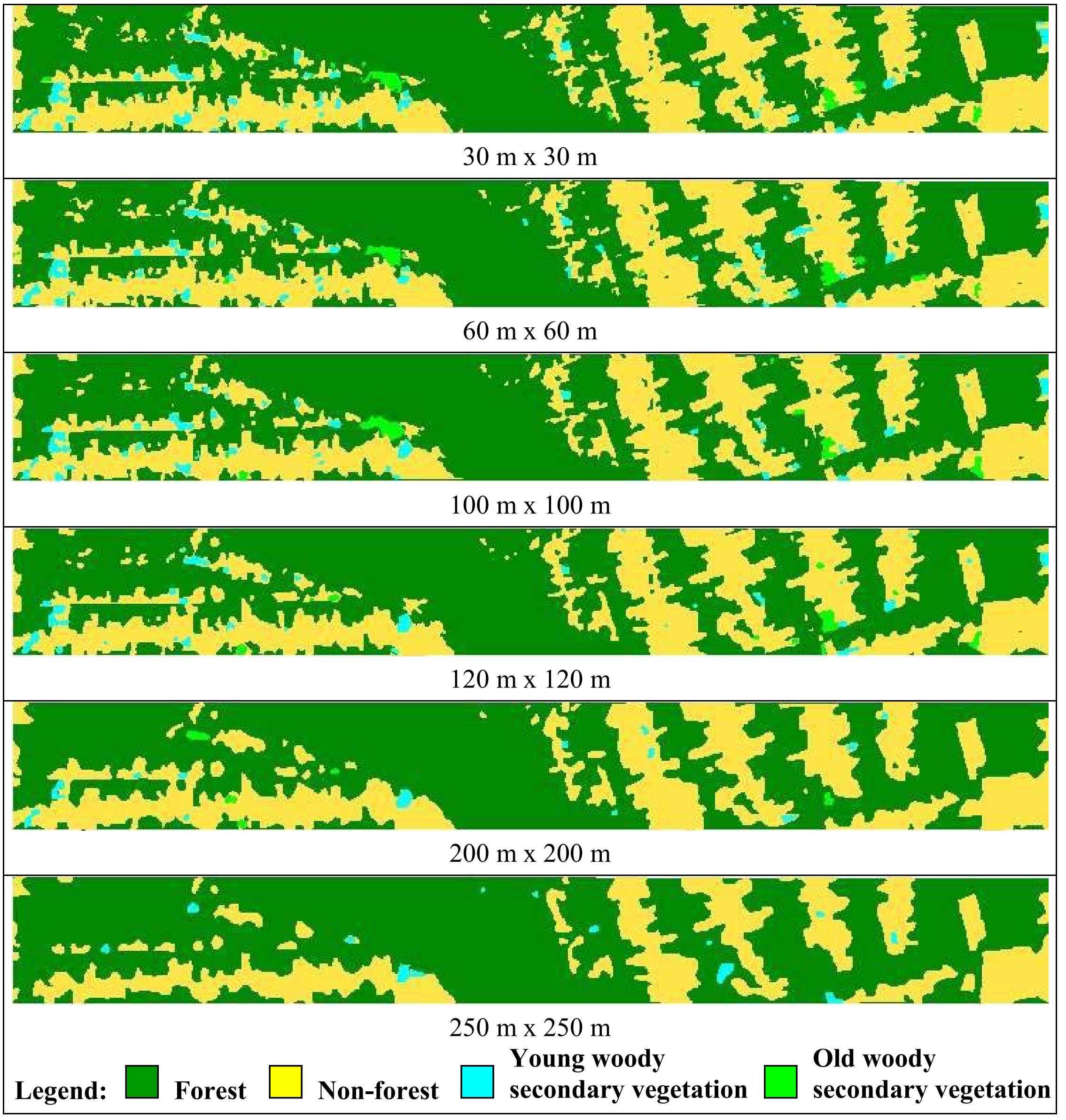
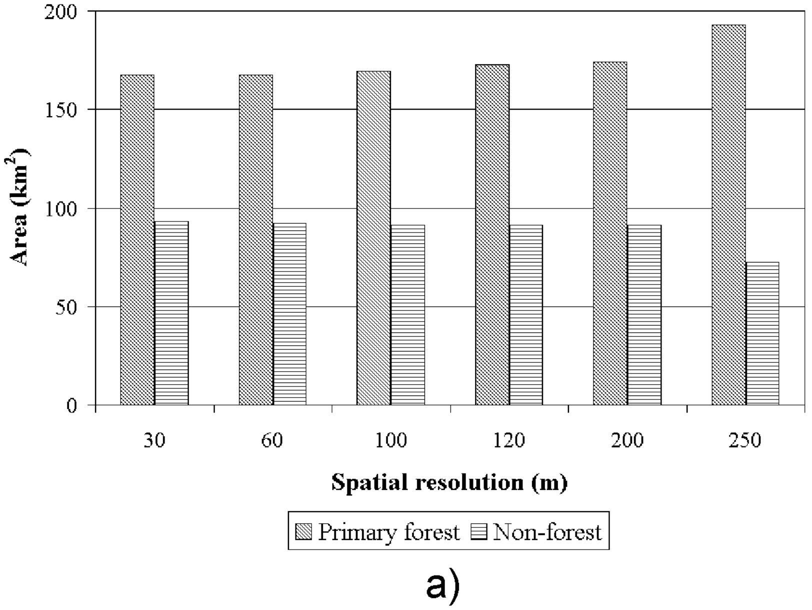


Fig. 2 – Thematic maps resulting from visual interpretation of the Landsat 5/TM images of Figure 1 with different simulated levels of spatial resolution.

for simulations with pixel size higher than 100 meters due to the small size of their polygons that tend to disappear with pixel size increase (Figure 3b). These results are in agreement with those achieved by Pax-Lenney and Woodcock (1997) who studied the effects of spatial resolution on the agricultural monitoring. According to Pax-Lenney and Woodcock (1997), productive land areas in Egypt were slightly underestimated at spatial resolutions of 120 meters due to landscape characteristics such as small average farm size, variable cropping schedules, and cultivation of peripheral lands. The present results also show that the spatial resolution of 500 meters recommended by Townshend and Justice (1988), as



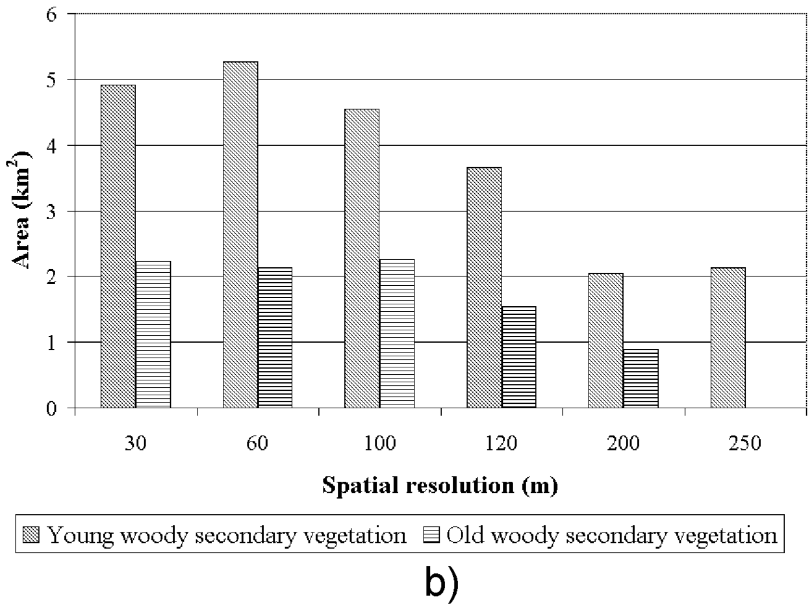


Fig. 3 – Area estimates for forest and non-forest in (a) and for old and young woody secondary vegetation in (b), as a function of the simulated spatial resolution values.

the best compromise between land change detection and data volume, would affect the accuracy of the identification of the woody secondary vegetation in the Amazon region.

Variations in Kappa coefficient, that represent the matched portion of a specific land cover class in the original (30 × 30 meters) and in the simulated images, are shown in Figure 4 for a variable spatial resolution. As indicated in this figure, the old and young woody secondary vegetation are the most sensitive land cover types to changes in spatial resolution due to their occurrence in small size polygons in the study area. Significant changes in accuracy values for these surface components are observed for simulations from 100 to 250 meters. From 30 to 250 meters, the old woody secondary vegetation was almost completely incorporated into the primary forest class because of the spectral similarity of these arboreal covers. In Figure 3b, the area of this land cover decreases from 2.24 km^2 (30 meters spatial resolution) to 0.12 km^2 (250 meters). On the other hand, the area of occurrence of the young woody secondary vegetation decreases from 4.95 km^2 to 2.13 km^2 with pixel size increase, and the remaining difference (error of visual interpretation) is interpreted mainly as primary forest and non-forest. Because land cover types are incorporated into the primary forest class in some extent with coarsening spatial resolution, there is a relative increase in the area of this class with pixel size increase, as shown in Figure 3a.

In Figure 5, when all land cover classes are considered, results from determination of the total Kappa coefficient show that the map accuracy tends to decrease for spatial resolution coarser than 100 meters.

4. CONCLUSIONS

The results indicated that the spatial resolution had a strong impact on the identification of old and young woody secondary vegetation in the Amazon environment due to the interaction of the size of these land cover types with the image spatial resolutions examined. The optimal value of spatial resolution for the identification of these land cover types was 100 meters due to the landscape characteristics of the woody vegetation regrowth in small average size abandoned areas. For spatial resolution coarser than 100 meters, significant changes in the calculated area of the woody secondary vegetation were observed in the study area. On the other hand, the optimal value for a simple discrimination between forest and non-forest areas was 200 meters. Spatial resolution coarser than 200 meters produces an increase in area of forest due to pixel incorporation of other land cover types (e.g., old woody secondary vegetation).

This result has important implications for the planned Brazilian equatorial orbit satellite SSR 1. Because of the optical design of the camera modules, pixel size should vary within the same scene according to the latitude of data acquisition (50 meters at nadir; 100 meters at S10º; and 200 meter at S15º). Since most of the critical areas of deforestation are located between S10º and S15º, the use of SSR 1 for identification of the woody secondary vegetation classes and deforestation estimates will be unreliable due to pixel size values higher than 100 meters at these latitudes.

This study is also important for global scale investigations by providing specific information on the relationships between the regional identification of Amazonian land cover types and the spatial resolution.

5. ACKNOWLEDGMENTS

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RESUMO

Para avaliar o papel da resolução espacial na discriminação de diferentes classes de uso da terra na região Amazônica, diferentes valores de resolução espacial (60, 100, 120, 200 e 250 metros) foram simulados a partir de uma imagem do sensor "Thematic Mapper" (TM) do satélite Landsat 5. Mapas temáticos foram elaborados através da interpretação visual tanto nas imagens originais (30 × 30m), quanto nas imagens simuladas. Na legenda foram incluídos a floresta primária, as sucessões secundárias inicial e avançada, e áreas de não-floresta. Os resultados indicaram que para os temas Floresta e Não-floresta as alterações na resolução espacial não exerceram influência marcante nas estimativas de suas áreas, até as simulações de 200 metros. O contrário se verificou na identificação

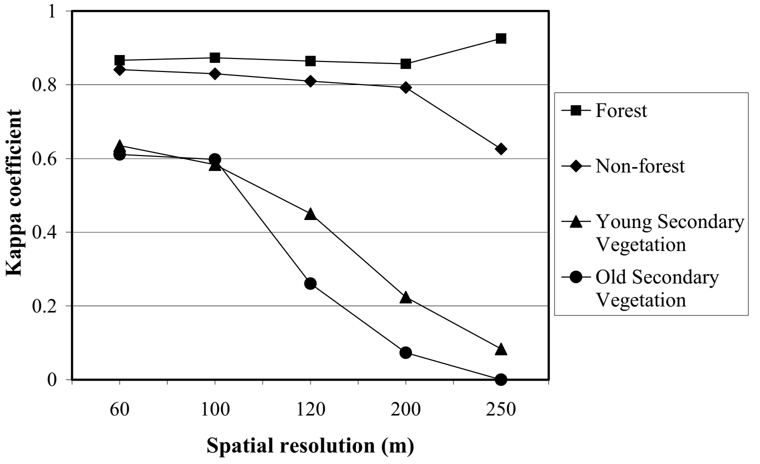

Fig. 4 – Kappa coefficients, calculated in relation to the mapping of the original Landsat 5/TM image (30 × 30 meters), for different land cover types and spatial resolution.

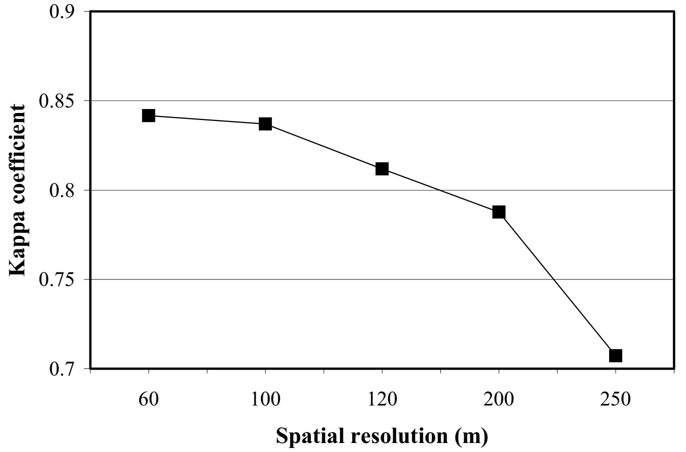

Fig. 5 –Total Kappa coefficients calculated from all land cover types.

das áreas das formações florestais secundárias, uma vez que elas ocorrem sob forma de pequenos polígonos. Para evitar mudanças significativas no cálculo de área dessas formações, uma resolução espacial melhor que 100 metros é necessária. Esse resultado é uma indicação de que o uso do futuro satélite brasileiro de sensoriamento remoto (SSR-1) para a identificação de vegetação secundária em paisagens semelhantes a essa da área de estudo pode ser dificultado, especialmente para latitudes entre S10^{o} e S15^{o}. Entre estas latitudes, estão localizadas áreas críticas de desflorestamento e o tamanho do pixel deverá variar em uma mesma tomada de cena entre 100 metros (S10^{o}) e 200 metros (S15^{o}).

Palavras-chave: resolução espacial, sensoriamento remoto, Amazônia, mapas temáticos, floresta tropical.

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