The Use of Landscape Metrics on Multi-temporal Forest-Non Forest Maps of Northeast Mato Grosso, Central Brazil.

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By

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Abstract

The continuing destruction of the Amazon Tropical Rain-forest is alarming due to its increasing rate. According to the National Institute for Space Research – INPE the state of Mato Grosso contributed to 44% of the total area deforested in the Legal Amazon for 2003. The region in the north-east of the state is characterised by ecotones and has been recognised as a priority area for conservation due to its endemic nature. Landsat images of the north-eastern region of Mato Grosso were used to produce forest/non-forest cover maps at three different periods (1992, 2000 and 2003). The thematic images produced were derived from an unsupervised classification using the maximum likelihood algorithm upon TM5/TM4 simple ratio images. The image was subdivided into 25 equilateral cells for the analysis of landscape metrics using FRAGSTATS. The results show a rapid expansion of large non-forest areas throughout the whole landscape, dramatically in the period between 2000 and 2003. The metrics used indicate that not only are forest patches disappearing (attrition), they are also getting smaller (shrinkage).

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Introduction

1 Introduction

The progressive modification of natural environments due to human activities has become a serious problem in the world today (Cardille and Foley, 2003; Vieira *et al.*, 2003; Mertens *et al.*, 2002; Millington *et al*., 2002; Adams, 1989). In many tropical regions, large-scale changes in land cover involve the replacement of the natural vegetation by crops or pastures (Costa *et al*., 2003) and cities (Adams, 19941989).

This phenomenon can be seen widely in developing countries, where the abundance of natural resources leads to its unplanned exploitation (Mertens *et al.*, 2002). According to Cruz (2003), developing countries have traditionally adopted a development model that prioritises economic progress to the detriment of better social conditions and environmental quality. The observed consequences of this model are the increase of social injustices (e.g. unemployment, slavery, hunger, etc.) and the decrease of available natural resources (e.g. water, land, forests etc.) (Cruz, 2003).

The Brazilian Legal Amazon, shown in Fig. 1, consists primarily of closed tropical forest but also includes large areas of savannah and its many ecotones, transition areas between distinct vegetation types (Carvalho *et al.*, 2003; Roberts *et al.*, 2003). The Legal Amazon covers an area of 5.8 million km^2, of which an estimated 15% has been cleared in the last 30 years (Houghton *et al*., 2000). This untouched landscape, proven to play an important role in the dynamic Earth System (Manobavan, 2003), has become a commodity to be explored by the globalised world (Bickel, 2004), including intensive scientific research by international organisations (Weiers *et al*., 2004; Cardille and Foley, 2003; Vieira *et al.*, 2003; Asner *et al.*, 1999; Asrar *et al.,* 1992).

The Bananal Island (Fig.2) is situated in an ecotone of the Amazon and Cerrado transition and has been acknowledged as an important site for conservation due to its delicate and complex nature (Gonçalves and Nicola, 2002). The island is protected by Indigenous Areas, a National Park and internationally accepted as a RAMSAR Site for Wetland Conservation (Ramsar Convention on Wetlands, 2004). The areas adjacent to the island have been subjected to ranch settlement by past governments.

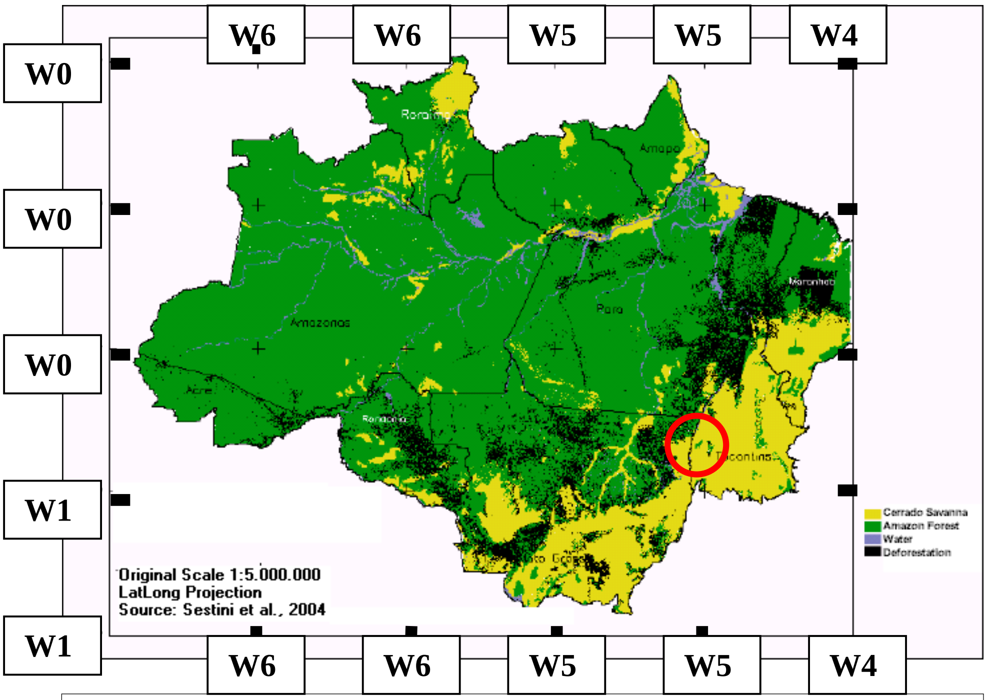


Fig.1. The Brazillian Legal Amazon, red circle is study area. (Sestini *et al.*, 2004.

It has already been suggested that monitoring efforts should concentrate on vegetation boundaries (ecotones) where plants are presumed to be near the edge of their physiological tolerance (Carvalho *et al*., 2003; Ivanauskas, 2002; Ferson *et al*., 1995).). Ecotones that, upon analysis, are especially sharp and obvious to

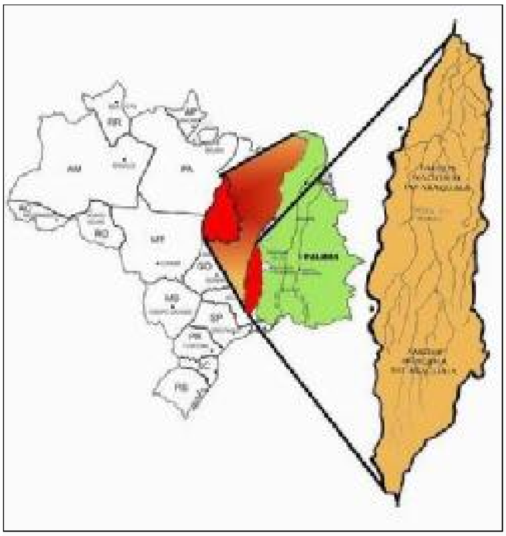


Fig. 2. Bananal Island, situated in Tocantins, is the largest natural fluvial island in the world with approximately 2 million hectares (Gonçalves &

observers are the least sensitive to the kinds of environmental alterations induced by global changes (*Ferson et al*., 1995). However, the classes of transition zones found at the Bananal Plain appear to be more subtle and are especially sensitive to environmental changes, being ideal for use as monitors of initial global changes (Ivanauskas, 2002).

The Brazilian government has proposed many development projects for this region, potentially putting at risk a highly diverse landscape and compromising its environmental integrity (Bickel, 2004). Analysing this region at a landscape perspective will improve our understanding of the environmental problems that arise from human activities and future planning and remediation may be facilitated. Therefore, this transition area provides peculiar socio-economic and environmental conditions worth focusing upon.

The development of landscape indices (metrics) and its application in land-cover information (thematic maps) has advanced and can help us assess, plan and monitor the territory. Remote sensing has been used to map land cover and quantify change in the Amazon for nearly 30 consecutive years (Roberts *et al*., 2003; Bentz, 1990). Spectral data obtained by the space-borne platforms are usually transformed into thematic features through the application of different classification techniques (Batistella, 2001; Boyd, 2000). The resulting thematic maps can be used to examine the temporal evolution of landscape mosaics (Millington *et al*., 2003; Botequilha Leitao and Ahren, 2002; Blanco Jorge and Garcia, 1997).

In this case study, MIR/NIR operations will be applied on three Landsat images to characterise the landscape according to the vegetation, furthermore an unsupervised classification will allocate pixels using the minimum distance algorithm as forest and non-forest covers. One Landsat-5 TM image of 1992 and two Landsat-7 ETM+ (2001, 2003) comprising an area west of the Bananal Island will be used to analyse its history of deforestation. Southworth *et al*. (2004), Millington *et al*. (2002), and Batistella (2001) have successfully described the deforestation processes at tropical regions through calculated landscape metrics. The hypothesis is that frontier expansion occurring in the Amazon-Cerrado region around the Bananal Plain can be demonstrated by the application of landscape metrics on multi-temporal land-cover data and can be used to formulate remediation strategies that minimise the consequences of unplanned frontier expansion. Therefore the objectives of this project are to acquire ortho-rectified remotely sensed data of the Bananal Plain, to produce thematic maps of the area and to compare and interpret its calculated landscape metrics.

Literature Review

2 Literature Review

2.1 Progress in the Legal Amazon?

The creation of SUDAM (Superintendence of the Amazon) by the Brazilian government in the 1960s established the Legal Amazon, creating incentives for the implementation of large-scale mineral, industrial and agricultural projects aimed for exportation (Cruz, 2003). The construction of a road system also encouraged an intense migratory rate into the Amazon and Cerrado, consequently generating the highest rate of population growth in the country (IBGE, 2003). By the 1980s, the technology developed by the state-owned agricultural enterprise EMBRAPA, along with the increasing number of farmers helped the advance of soybean and other mechanised cultures into the Amazon (Bickel, 2004). The increasing demand for these cultures in the international market created a conflict between development and preservation of the largest tropical forest in the world (Mertens *et al*. 2002; WWF, 2003; Bickel, 2003), including conflicts with native tribes and conservation units (Gonçalves and Nicola, 2003). In addition, the highly mechanized cultures employed few people and with a high demand for external capital, have resulted in a concentration of land and gains (socio-economic injustice)(Bickel, 2004).

The social and environmental impacts that arise from this frontier expansion are evident after considering the costs of externalities found in the mechanised production of soy and other cultures utilising herbicides. According to Pretty (2000), the total cost of unemployment, medical treatment, remediation of pollution, ecosystem restoration, and loss of environmental services in a production system of direct planting with herbicides is estimated to be at US$180/ ha/ year. In Brazil, the area managed under this system was estimated at 18m hectares in 2002/2003

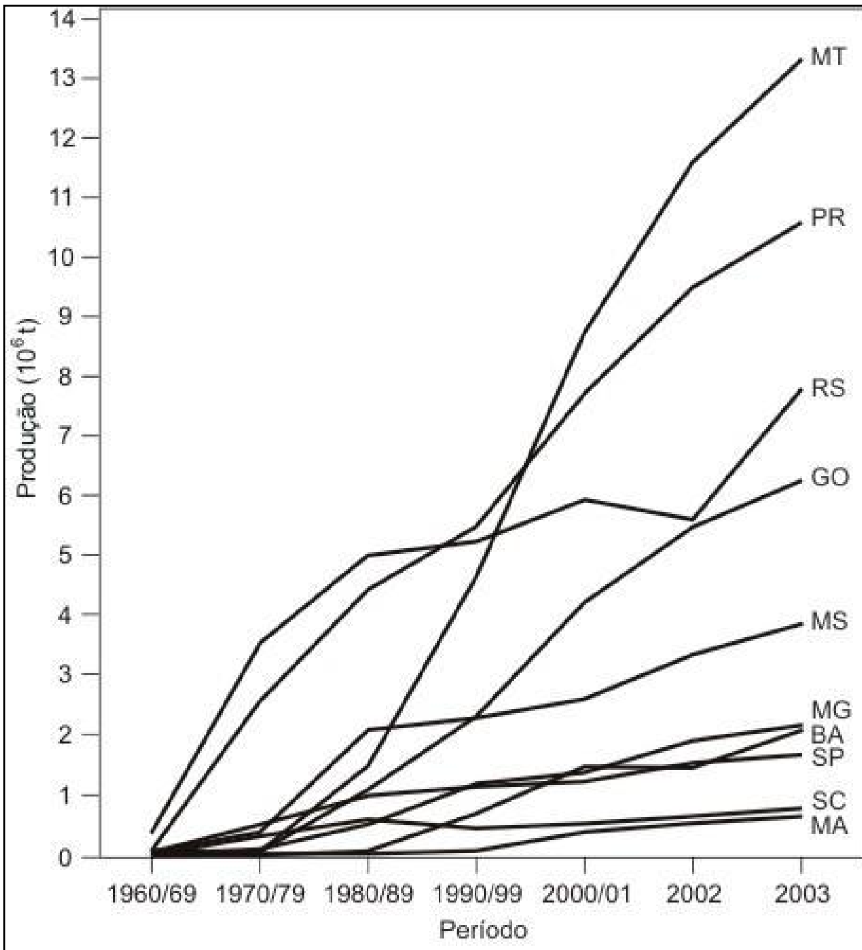


FIG. 2. Produção de soja no Brasil - Evolução por estado.

Figure 3. Soya Production per Brazilian state, IBGE, 2004.

More recently, a proposal to create the Araguaia-Tocantins Waterway would have affected 35 indigenous areas and could have led to the explosion of 87 natural dikes in the Araguaia River (International Rivers Network, 1998). This major project was postponed due to resistance of native tribes and environmentalists and is now to be rejected after an Environmental Impact Assessment proved it not viable (Gonçalves e Nicola, 2002; International Rivers Network, 1998).

2.2 The Bananal Island and its surroundings

The area of this study is specifically located at Lat: 12:07:06S (-12.1183) Lon: 51:26:21W (-51.4391). It is located in the northeast of Mato Grosso state, at a divisor of two important watersheds (Araguaia / Xingu) (Figure 3.). The Bananal Island is the largest fluvial island in the world (2m hectares), formed by the confluence of the Araguaia and Javaés Rivers (Gonçalves and Nicola, 2002). The vegetation between the Amazon tropical forests and the Cerrado savannas in this region is characterised by ecological tension between two distinct vegetation types (Carvalho *et al.*, 2003), where ecotones and encraves can be frequently found, hosting a high biodiversity and many endemic species. The periodically inundated landscape has the uniqueness of also having characteristics and species of a third Biome, the swampy Pantanal (Carvalho *et al.*, 2003; Gonçalves and Nicola, 2003; Ivanauskas, 2002;).

This complex mixture of different ecosystems creates a delicate dynamic balance, regulated by the different climatic, geomorphologic and geologic profiles there present (Ivanauskas, 2003; Novaes?). Such is the ecological importance of the island that by 1959 most of it had been recognised as an environmental reserve by the government and in 1971 established as an Indigenous Park due to the presence of large native tribes (Gonçalves & Nicola, 2002). The later establishment of the Araguaia National Park in 1983 ensured the legislative protection of the northern tip of the island (IBAMA, 1998).

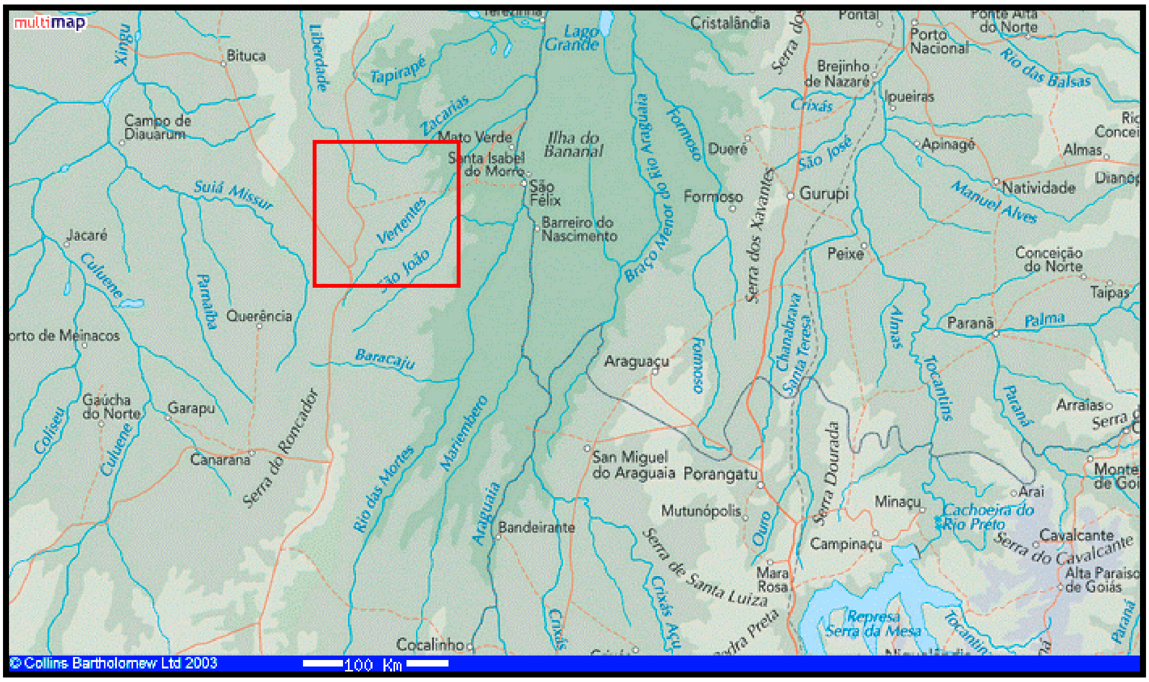


Fig. 04. Map of Bananal Island and its surroundings. The study area is marked in red. Source: Multimap, 2004.

The presence of three indigenous tribes (Tapirapé, Karajá, Javaé and Xambioá), ranch farmers and major grain farmers creates a diversified socio-economic profile. The more recent appearance of eco-tourism in the region explores the potential to develop the economy in a sustainable manner.

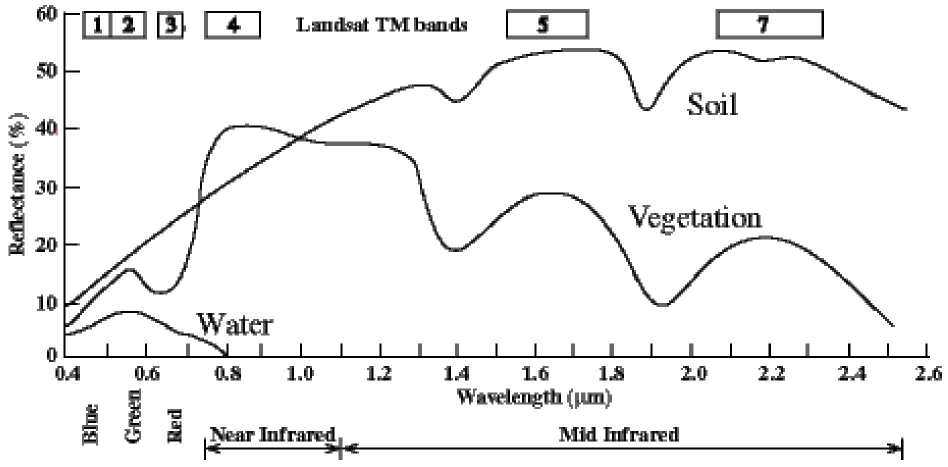
2.3 Remote Sensing and Image Classification

Planning based on ecological and socio-economic parameters is essential in the process of correctly assessing and zoning the territory (Mendonça-Santos and Claramunt, 2001; Simberloff and Abele, 1982). Remote sensing and GIS (geographic information systems) are important and useful tools with numerous applications, one of which is the use of landscape metrics in land-cover information (Trindade-Galo and Moraes Novo,____).

NASA successfully placed the Landsat-7 sensor in orbit in 1999 (GLCF, 2004). Masek *et al*. described the Enhanced Thematic Mapper as essentially replicating the unsuccessful EOSAT Landsat-6, with seven spectral bands including a 15m panchromatic band as well as a 9-bit analog to digital converter. The spatial resolution of the thermal infrared band has been improved from 120 to 60m, and there is an addition of (Full / Partial) Aperture Calibrators to allow solar calibration of the instrument. This has resulted in an overall improvement in the sensor's performance in geodetic systematic correction, with the ability to automatically navigate pixels to within ~50m of the actual ground location (Masek et al. 2001).

Given the improved information content in bands 2 and 3, subtle land-cover features in dark targets such as water and forests can be recorded. This suggests the possibility to recover variations attributable to vegetation phenology and health. The addition of the panchromatic band, with 15m spatial resolution, has allowed for the increased accuracy in land-cover classification and precision in coregistration, both of which are essential in change detection.

Classification schemes based on the spectral response of land features are commonly adopted to extract thematic information from multi-spectral data. There are two basic types of classification schemes: Unsupervised and Supervised Classification. The unsupervised method relies on the application of algorithms to automatically identify clusters of pixels with similar spectral identities (Jensen, 1986). This is a quick and objective way to obtain a preliminary identification of the possible land features (Boyd, 2000).



(Adapted from Richards & Jia 1999)

Figure 5. Spectral reflectance of a few known materials.

On the other hand, the supervised classification relies on the identification of sites to represent specific categories of land cover, from which an algorithm will subsequently allocate each pixel in the predetermined categories. This method is dependent on the subjective interpretation of land features and is usually site-specific.

The development of vegetation indices has helped the process of measuring forest stand parameters from remotely sensed images (Carlson and Ripley, 1997). The information generated by the operation between different spectral bands have been proven to correlate with parameters such as aboveground biomass and stand structure. A recent study by Lu et al. (2004) have found that vegetation indices that use the red (TM3) and near infrared (TM4) spectral bands correlate more poorly with forest stand parameters than indices calculated with the near infrared (TM4) and mid infrared (TM5). It was found that a simple TM4/TM5 ratio image was significantly correlated to AGB (Above Ground Biomass) and BA (Basal Area) and strongly correlated to ASD (Average Stand Diameter) and ASH (Average Stand Height) (Lu *et al*., 2004).

2.4 Landscape Ecology

Landscape ecology has emerged as a way to explore how a heterogeneous combination of ecosystems is structured, functions and changes (Forman and Godron, 1986). That said, the three fundamental characteristics when studying the ecology of landscapes are structure, function and change. Turner (1989) describes how the spatial structure influences most fundamental ecological processes, and how landscape planning, and subsequent management, influence landscape structure. Changes in the landscape structure will cause a change in the landscape function and vice-versa, like an endless feedback loop.(Forman and Godron, 1986). In this study the main focus will be on the analysis of the landscape structure.

Three fundamental landscape structural elements have been identified: patches, corridors, and matrix – that together constitute the widely accepted "Patch-Corridor-Matrix model" (Forman, 1995). It is a basic approach where the patches are distributed along the landscape matrix, either isolated or connected by corridors. This method can be used to describe the landscape and identify habitat fragmentation.

Habitat fragmentation has been recognised by Sorell (1997) as one of the greatest threats to biodiversity worldwide. There are three major components to fragmentation:

- Attrition, or the complete loss of the original habitat,
- Shrinkage, or the reduction in habitat patch size, and
- Isolation, or the increasing distance between habitat patches (Andren, 1994).

According to Fahrig (1997) attrition has the greatest impact on the environment. The effects of isolation are also significant. It results in a potential loss at a genetic level because it reduces the exchange among populations and can contribute to the extinction of species with metapopulation structure (McGarigal, 1998).

Landscape heterogeneity and habitat fragmentation processes (shrinkage, isolation, and attrition) are spatially measurable characteristics and processes. Landscape metrics enables these processes to be measured quantitatively for a better understanding of the landscape. They describe the spatial structure of a landscape at a specific point in time. Landscape metrics are tools that characterise the geometric and spatial properties of a patch (a spatially homogeneous entity) or of a mosaic of patches (Fortin, 1999).

Landscape structure can be characterised by its composition and configuration. Composition metrics measure landscape characteristics such as patch proportion, richness, evenness or dominance and diversity. Composition metrics require a classification of the landscape into different classes. On the other hand, landscape configuration relates to patch geometry and spatial distribution of patches.

Metrics can be calculated at three different levels. Patch metrics calculates parameters such as the size and shape of each individual patch. Class metrics measure the characteristics of a particular class (forest or nonforest) such as the number of patches for each class, the percentage of the landscape occupied by that class etc. Metrics at the landscape level returns the values for the whole landscape regardless of number of classes.

In the USA, some landscape metrics have been used as indicators for watershed integrity, landscape stability and resilience and biotic integrity and diversity (EPA, 1994). In Europe, the Joint Research Centre of the European Community has suggested metrics-based approaches utilising remotely sensed images to develop biodiversity indicators at the landscape level (JRC, 1999).

Re-establishing the connectivity of habitats provides a good example for the application of landscape ecological concepts and metrics. Connectivity is an important and measurable landscape characteristic. It is a parameter of landscape function and an important issue when assessing, or planning for biodiversity (Bennett, 1998). It has been well recognised that habitat connectivity is important to the persistence of both animal and plant populations in fragmented landscapes (Forman and Godron, 1986; Noss, 1991; Forman, 1995; Schumaker, 1996; Bennett, 1998).

Connectivity is fundamental to spatial concepts that support land-use planning and conservation strategies (Van Lier, 1998). The greenways movement has been active in implementing ecological networks internationally (Fabos and Ahern, 1995). The European Ecological Network (EECONET) is also based largely on the concept of connectivity (Bennett, 1995).

Connectivity metrics have been applied to model ecological processes, e.g. to obtain average isolation and predict the relative connectivity of habitat islands (Gustafson, 1998). Connectivity metrics are based on network theory and explicitly consider physical connections, e.g. corridors and hedgerows (Forman and Godron, 1986; Sklar and Constanza, 1991; Forman, 1995; Gustafson, 1998). The two commonly used methods used in geography to evaluate network connectivity are the gamma index and the alpha index, based on graph theory and also called circuitry (Forman and Godron, 1986; Forman, 1995).

Material and Methods

3 Materials and Methods

3.1 Data acquisition and preparation

The satellite images used for the landscape analysis were downloaded via an FTP service provided by the Global Land Cover Facility (GLCF, 2004). Two images (1992 and 2000) have been processed to Orthorectified level by the USGS/NASA (Figure 4a and 4b). The 2003 image has been processed to x level (Figure 4c). The images were subset at coordinates and further subdivided into 25 grid cell of 94.464 ha each (Figure 5.):

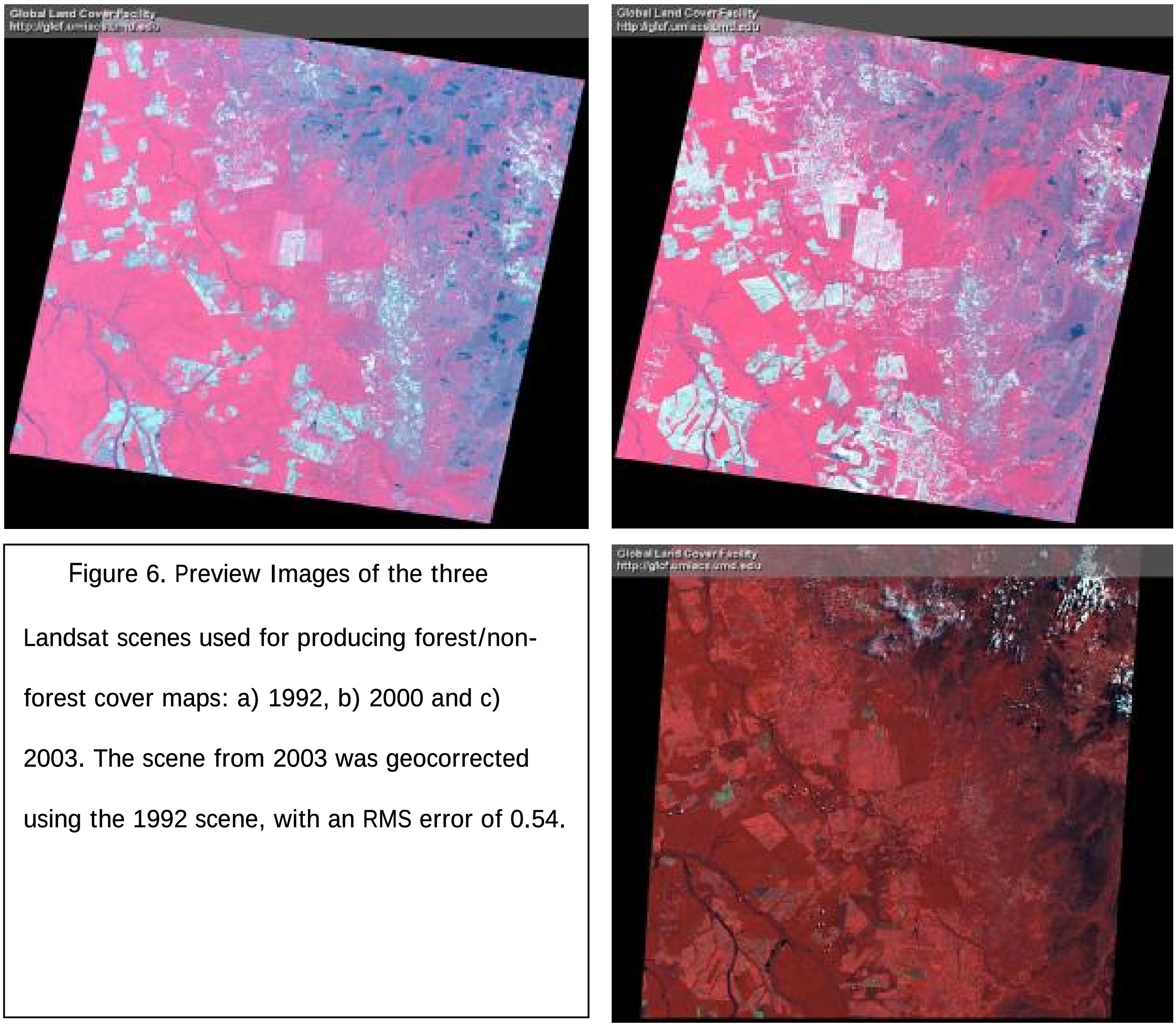


Figure 6. Preview Images of the three Landsat scenes used for producing forest/non-forest cover maps: a) 1992, b) 2000 and c) 2003. The scene from 2003 was geocorrected using the 1992 scene, with an RMS error of 0.54.

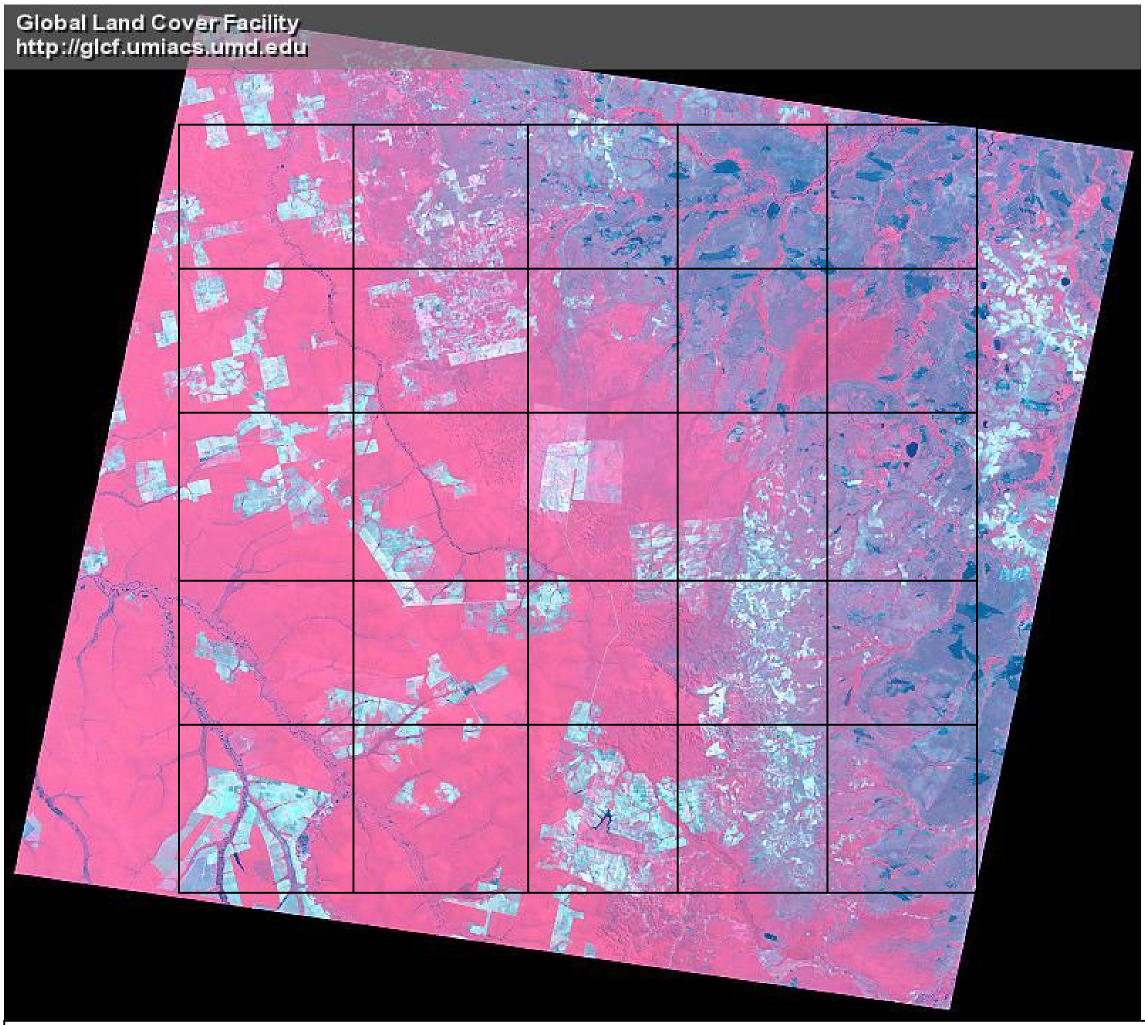


Figure 5. Representation of the subdivision made to the Landsat scenes. In the calculation of the metrics all cells have the same total area and are equilateral.

3.2 Image Classification

The application of the landscape metrics was made to land cover data-sets derived from TM4/TM5 simple ratio images. The application of this simple ratio has been proven to have a more significant correlation to forest stand parameters and was adopted as an alternative to the classic classification schemes. In this method, the simple ratio images are used in an unsupervised classification algorithm of maximum likelihood to produce a two-category image (forest and non-forest).

3.3 Metrics

The binary data sets produced by the unsupervised classification were transformed into 8-bit signed integer format for compatibility with FRAGSTATS v3.1. Different metrics were calculated for the whole landscape and for each individual cell. The formulas and a description of the computed metrics follows:

3.3.1 Landscape Metrics

Largest Patch Index -LPI: LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); Largest patch index quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance. LPI approaches 0 when the largest patch in the landscape is increasingly small. LPI = 100 when the entire landscape consists of a single patch (McGarigal and Marks, 1995). This metric was calculated for the whole landscape and for each of the 25 cells.

$\mathrm{LPI} = \frac{\max(a_{ij})}{A}(100)$	a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).

Number of Patches -NP: Number of patches is a simple measure of the extent of subdivision or fragmentation of the landscape, although it is more easily interpreted alongside with other metrics. This metric was also calculated for both the whole landscape and for each individual cell.

$NP = N$	N = total number of patches in the landscape.

Landscape Shape Index -LSI: Landscape shape index provides a standardized measure of total edge or edge density that adjusts for the size of the landscape. Because it is standardized, it has a direct interpretation. LSI can also be interpreted as a measure of patch aggregation or desegregation, similar to the class-level interpretation. Specifically, as LSI increases, the patches become increasingly disaggregated. Calculated for landscape and cells.

$LSI = \frac{E}{\min E}$	E = total length of edge in landscape in terms of number of cell surfaces; includes all landscape boundary and background edge segments. min E = minimum total length of edge in landscape in terms of number of cell surfaces (see below).

3.3.2 Class Metrics

Percentage of Landscape -PLAND: Percentage of landscape quantifies the proportional abundance of each patch type in the landscape. Like total class area, it is a measure of landscape composition important in many ecological applications. This metric will be calculated for the whole landscape and the 25 cells.

$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	P_i = proportion of the landscape occupied by patch type (class) i. a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).

Number of Patches -NP: Number of patches is a simple measure of the extent of subdivision or fragmentation of the class. This metric was calculated for both the whole landscape and for each individual cell.

$NP = n_i$	n_i = number of patches in the landscape of patch type (class) i.

Largest Patch Index -LPI: LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); Largest patch index quantifies the percentage of total landscape area comprised by the largest patch of a particular class. This metric was calculated for the whole landscape and for each of the 25 cells.

$LPI = \frac{\max\limits_{j=1}^{n}(a_{ij})}{A}(100)$	a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).

3.3.3 Patch metrics (25 cells only)

Area -AREA: area of the patch in hectares.

$AREA = a_{ij}\left(\frac{1}{10,000}\right)$	a_{ij} = area (m^2) of patch ij.

Perimiter -PERIM: perimeter of the patch, including any internal holes in the patch.

$PERIM = p_{ij}$	p_{ij} = perimeter (m) of patch ij.

Fractal Dimension -FRAC: degree of complexity of patches based on a perimeter-to-area ratio.

$FRAC = \frac{2 \ln (.25\, p_{ij})}{\ln a_{ij}}$	p_{ij} = perimeter (m) of patch ij. a_{ij} = area (m^2) of patch ij.

Core area -CORE: represents the area in the patch greater than the specified depth-of-edge distance from the perimeter, in this case 250m.

$\mathrm{CORE} = a_{ij}^{c}\left(\frac{1}{10{,}000}\right)$	a_{ij}^{c} = core area (m^2) of patch ij based on specified edge depths (m).

Number of disjunct core areas –NCORE: equals the number of disjunct core areas contained within the patch boundary.

$\mathrm{NCORE} = n_{ij}^{c}$	n_{ij}^{c} = number of disjunct core areas in patch ij based on specified edge depths (m).

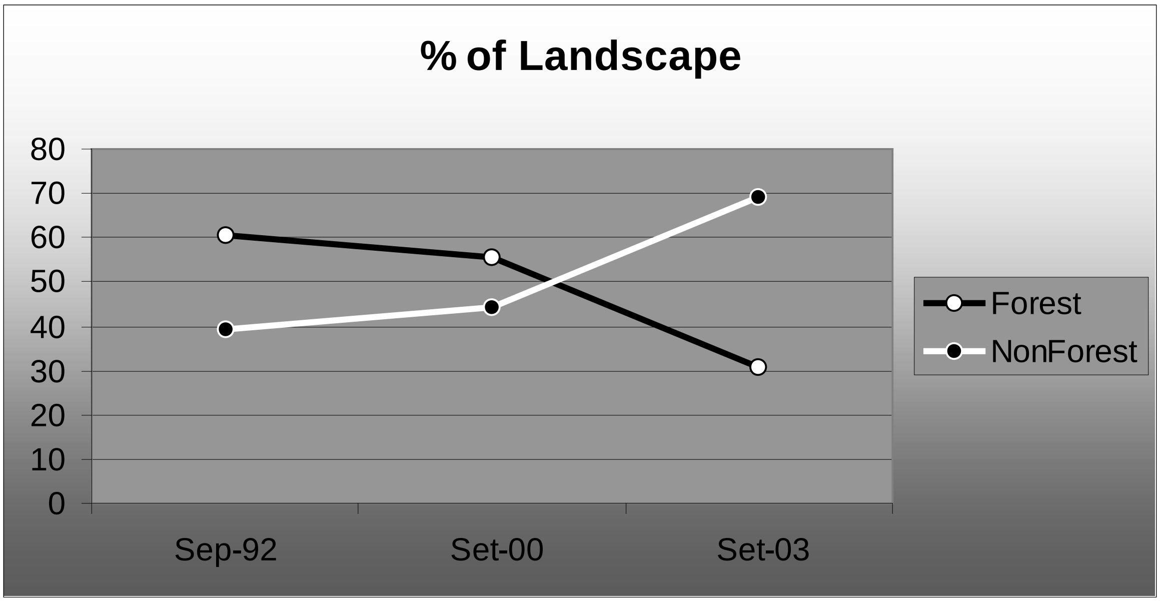
Radius of gyration –GYRATE: equals the mean distance (m) between each cell in the patch and the patch centroid. Radius of gyration is a measure of patch extent; thus it is affected by both patch size and patch compaction.

$\mathrm{GYRATE} = \sum_{r=1}^{z} \frac{h_{ijr}}{z}$	h_{ijr} = distance (m) between cell ijr [located within patch ij] and the centroid of patch ij (the average location), based on cell center-to-cell center distance. z = number of cells in patch ij.

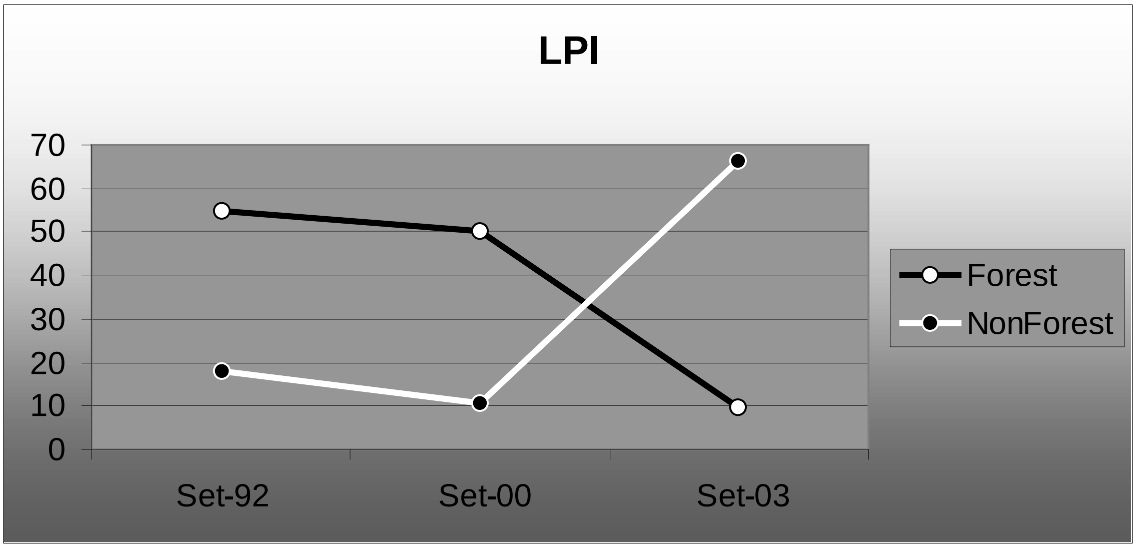
Results

4. Results

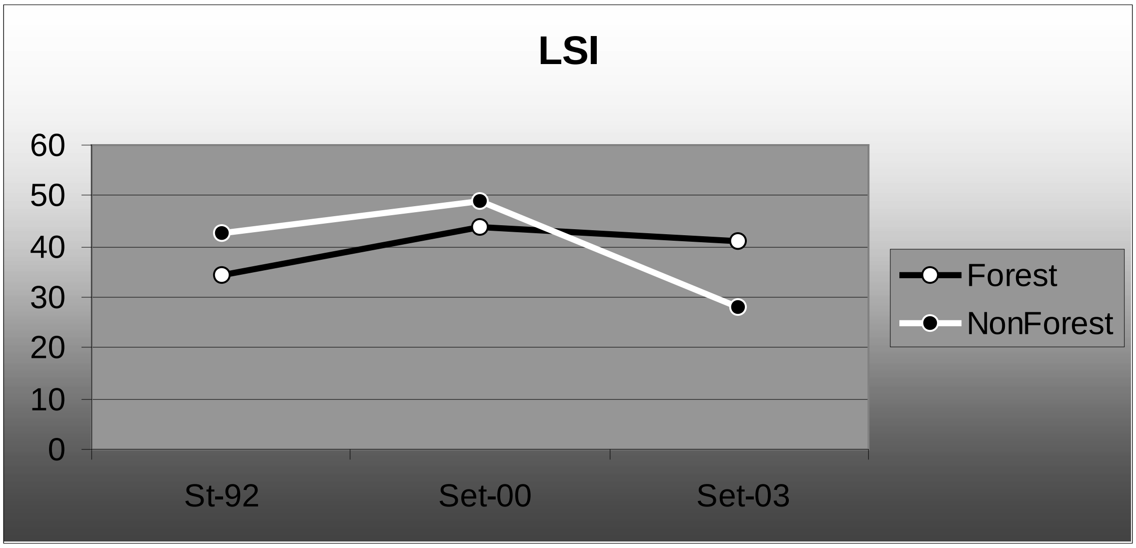
The images produced by the TM5/TM4 operation (Appendices 1, 2 and 3) were used in the unsupervised classification, which in turn produced the 'Forest-NonForest' maps (Appendices 4, 5 and 6). The metrics calculated for the whole scene (Appendix 7) can be visually interpreted in a time sequence, shown in Graphs 5, 6, 7, and 8:



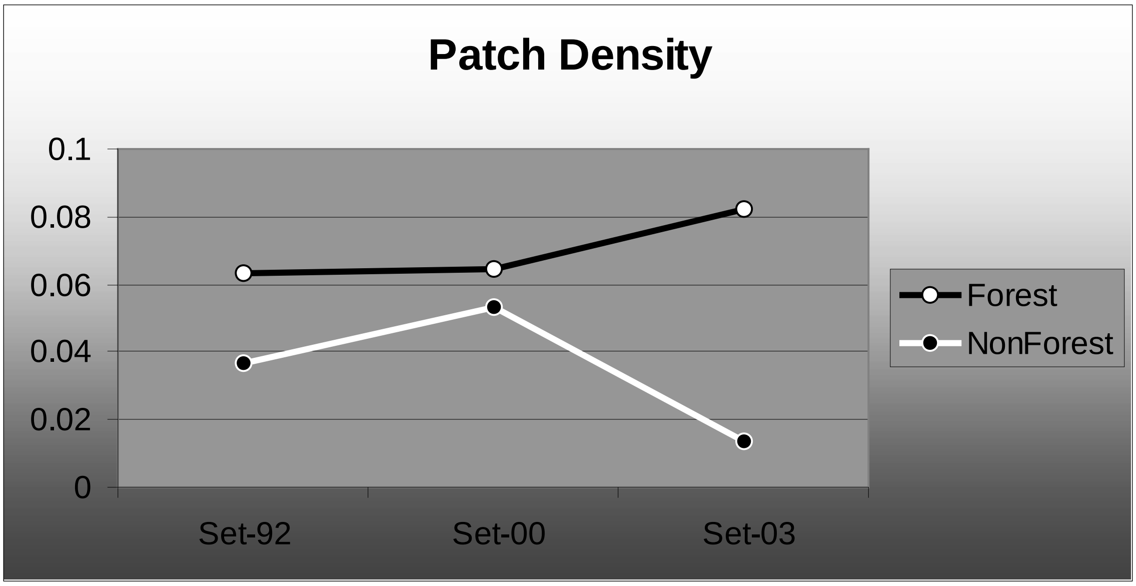
Graph 1. Percentage of Landscape per class (Forest-NonForest) for the whole landscape. NonForest patches occupied less area of landscape than Forest patches in 1992. During the first 8-year period NonForest only increased its area by approx. 5%. Where as in the 3-year period from 2000 to 2003, NonForest patches increased dramatically by approx. 25%.



Graph 2. Largest Patch Index per class (Forest-NonForest). NonForest patches occupy less area than Forest patches in 1992, both classes decreased during the first 8-year period and NonForest remained lower than Forest. From 2000 to 2003 the Largest patch of NonForest significantly increased their representation in the landscape.

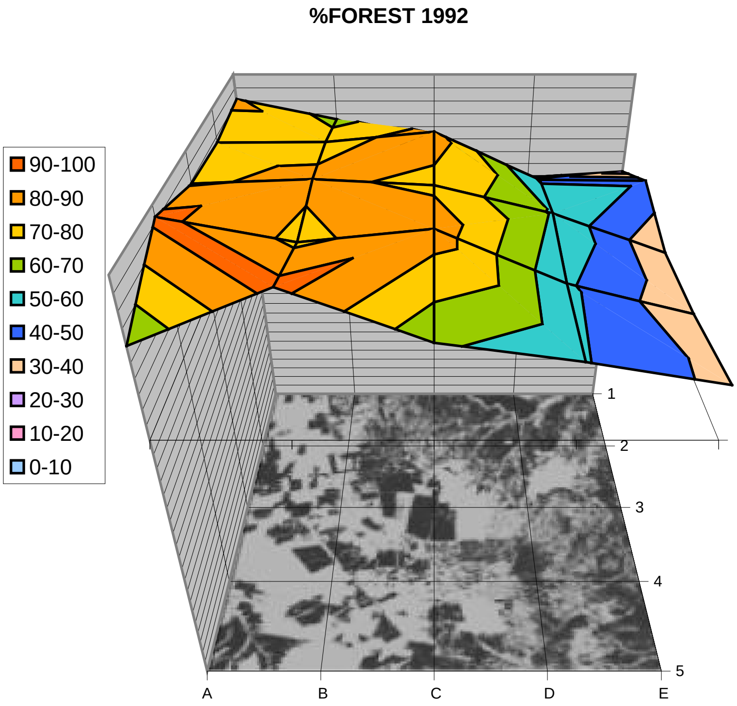


Graph 3. Landscape Shape Index per class (Forest-NonForest). NonForest patches had more edges than Forest patches in 1992, both classes increased during the first 8-year period and NonForest remained higher than Forest. From 2000 to 2003 both classes decreased in amount of edges, but NonForest much more accentuated, resulting in an LSI lower than Forest.

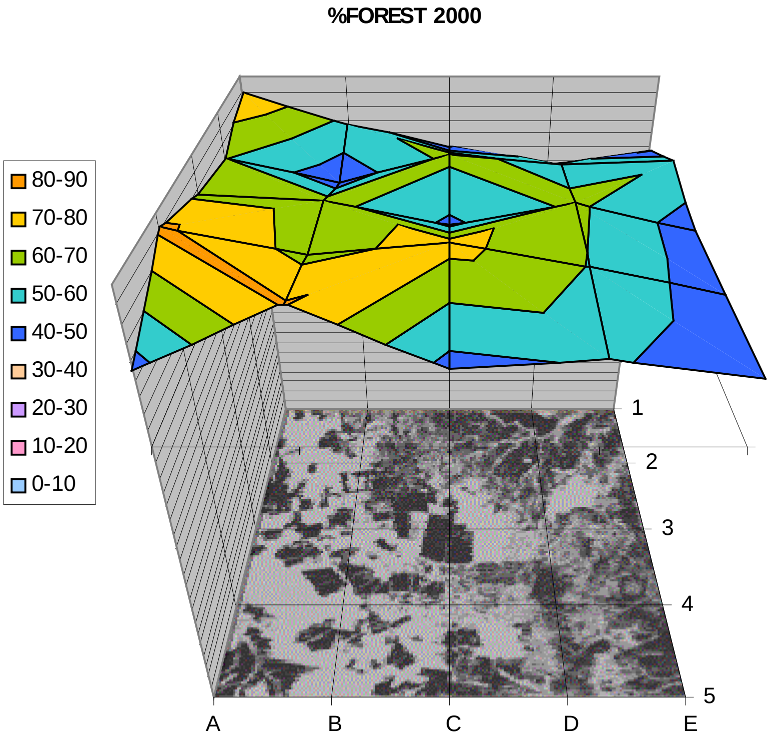


Graph 4. Patch Density per class (Forest-NonForest). There were less NonForest than Forest patches in 1992. Forest patches remained constant during the first 8-year period while Non-Forest patches increased. From 2000 to 2003 NonForest patches decreased while Forest patches increased in number.

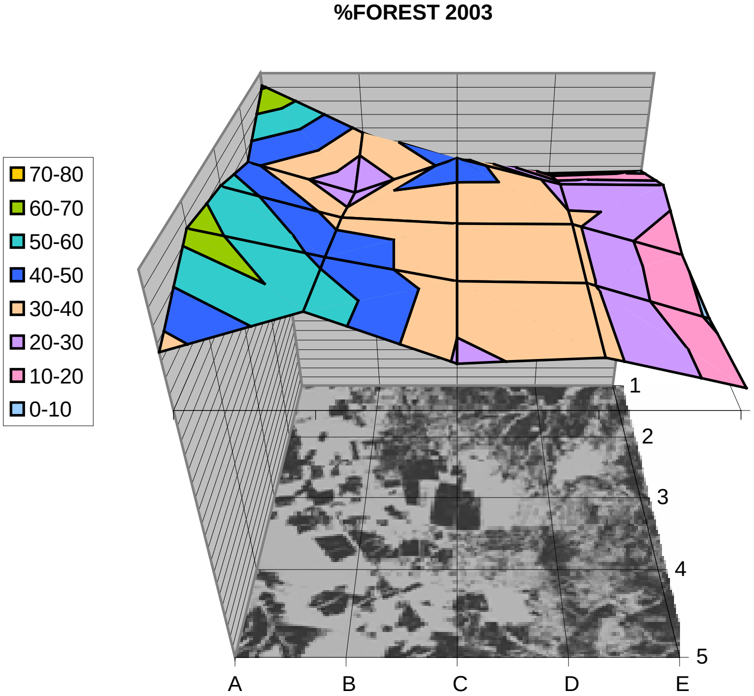
The percentages of forest for each of the subset cells have been plotted in Graphs 5, 6 and 7.



Graph 5. Percentage of Forest cover per cell, 1992.

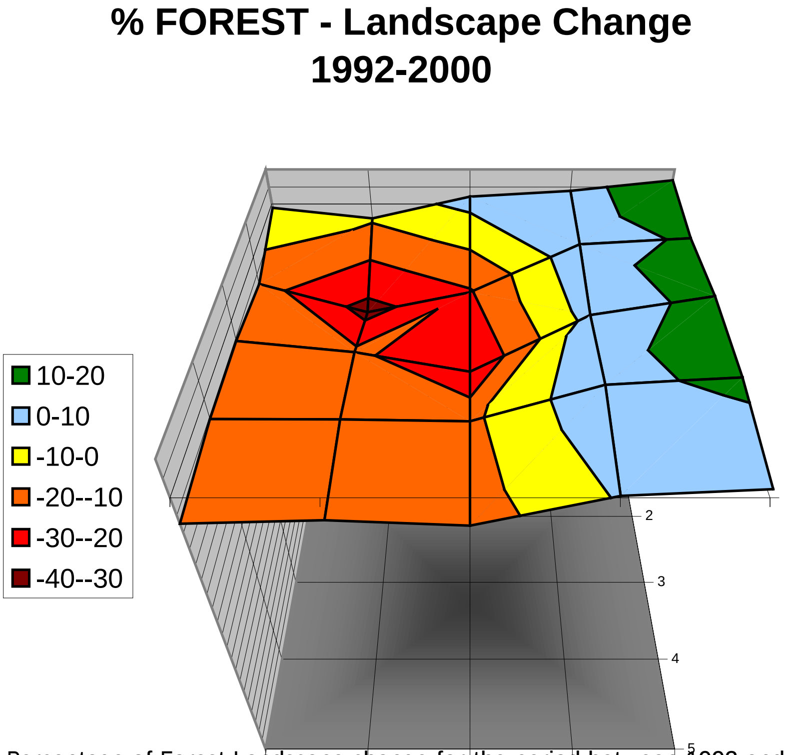


Graph 6. Percentage of Forest cover per cell, 2000.

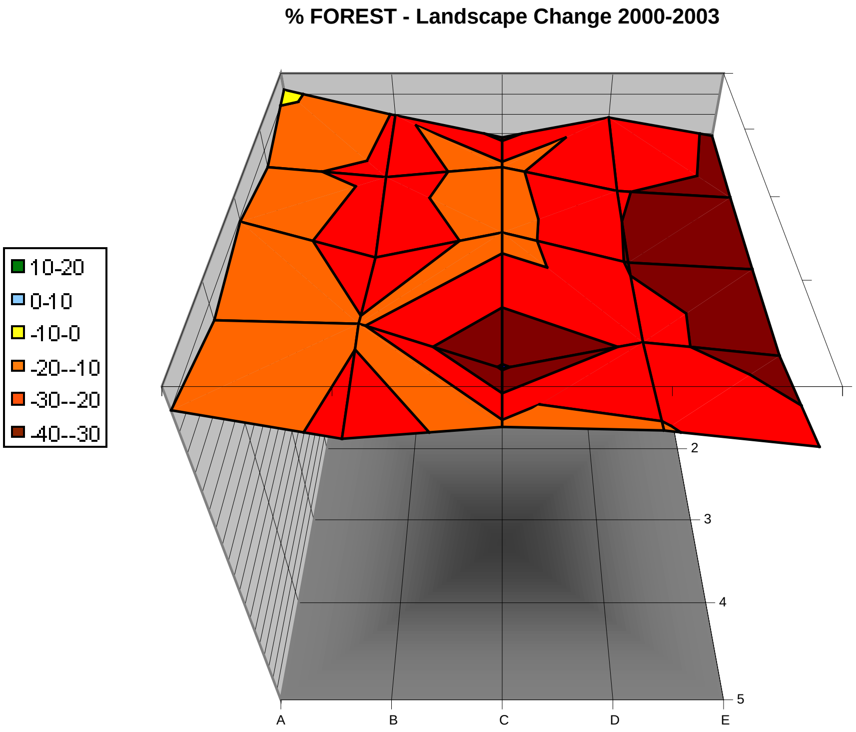


Graph 7. Percentage of Forest cover per cell, 2003.

To analyse the landscape change, the differences occurred between the periods have been plotted in Graphs 8 and 9:

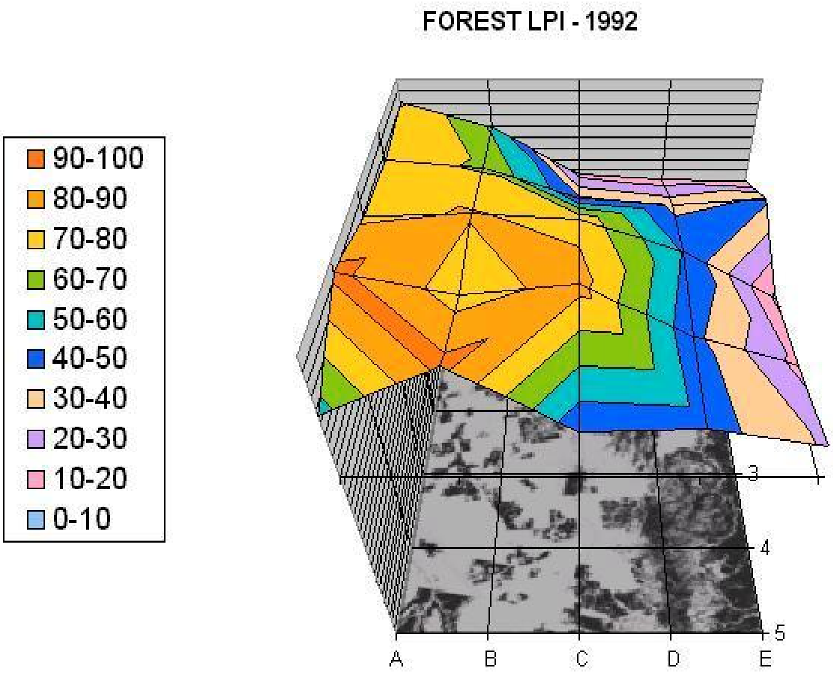


Graph 8. Percentage of Forest Landscape change for the period between 1992 and 2000.

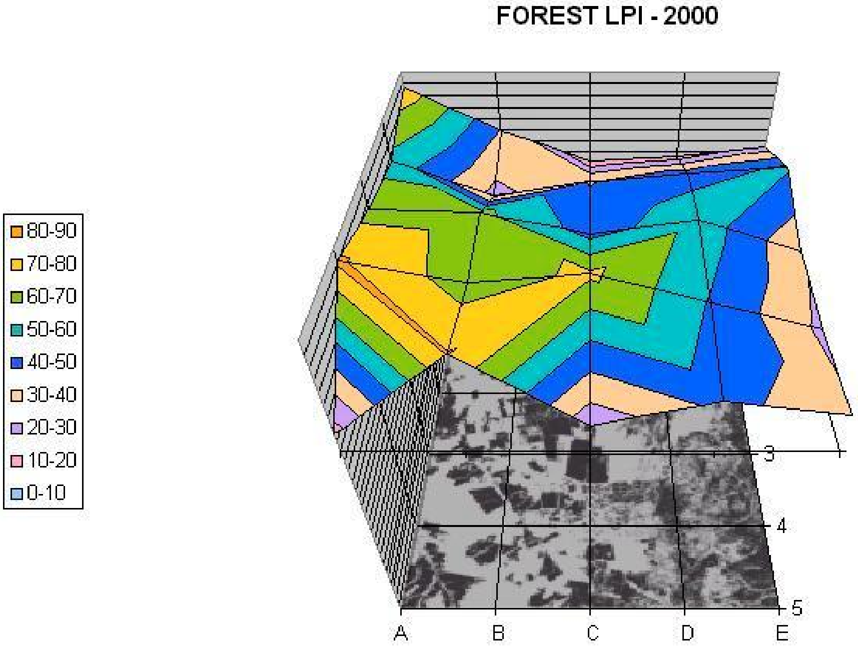


Graph 9. Percentage of Forest Landscape Change for the period between 2000 and 2003.

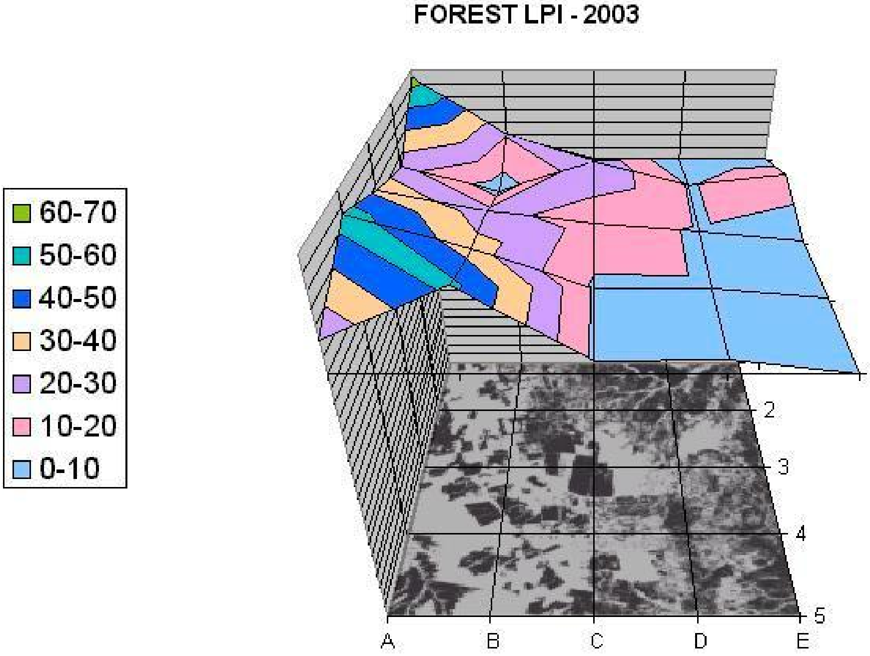
The Largest Patch Index (LPI) for each of the cells have been plotted in Graphs 10, 11 and 12:



Graph 10. Largest Patch Index for 1992

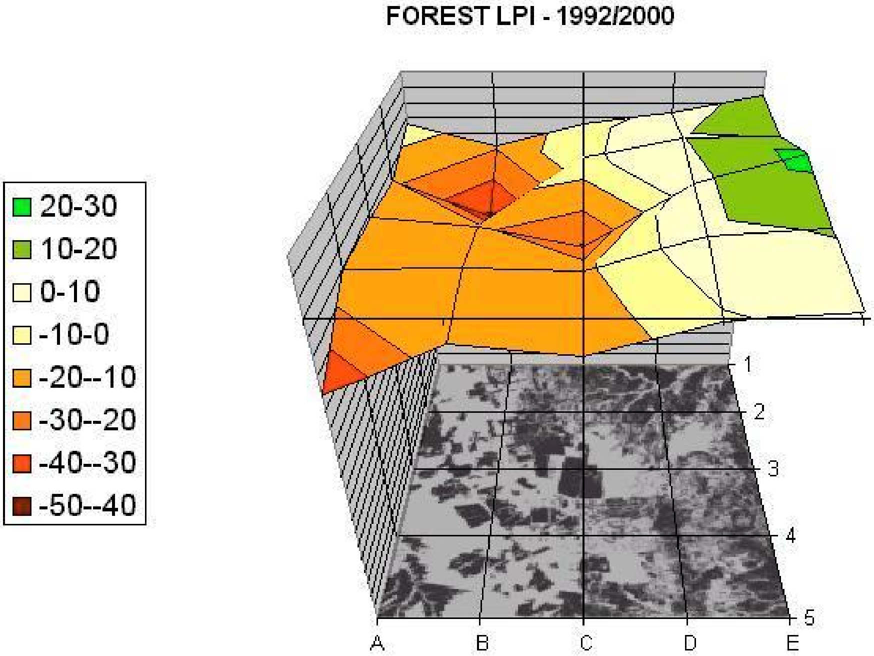


Graph 11. Largest Patch Index for 2000.

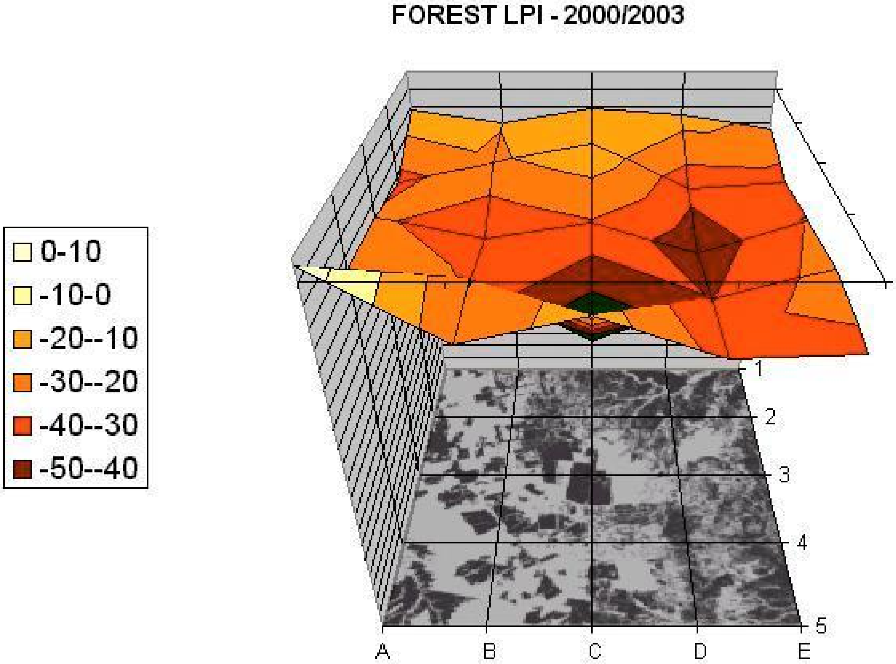


Graph 12. Largest Patch Index for 2003.

To analyse the change between periods, the difference was plotted in graphs 13 and 14:



Graph 13. Landscape change (LPI) for the period between 1992 and 2000.



Graph 14. Landscape change (LPI) for the period between 2000 and 2003.

Discussion

5. Discussion

Deforestation rates are increasing at alarming rates, and it has been noted that Mato Grosso is a major contributor to that. The region focused on this study is very ecologically important due to its endemic nature, hosting many species found nowhere else. The results of the landscape metrics analysis demonstrate the accelerated form which deforestation has taken place from 2000 to 2003.

Considering the fact that Brazilian legislation establishes very clear that no rural property cam cut down more that 50% of its original natural vegetation, not enoughg is being done to overcome this problem. The results have shown that more than 50% of the whole study area has now been converted to some form of non-forest feature, be it plantation, grazing fields or water dams.

The trends shown for percentage of landscape comprised of non-forest leads us to believe that from 1992 to 2000, the growth of big plantations (cells B2 and C3) were mainly located near the only highway, which cuts the study area in the north-south direction on the western side. During the first period (1992-2000), there was an actual increase in forest areas on the eastern side of the study area. But this trend is ephemeral, and during the second period (2000-2003), the whole landscape is subject to massive land-cover alterations, this time more dramatically.

The presence of native tribes which have been displaced by the government in the past may be a factor. The Tapirape tribe is the rightful owner of a massive reserve, which is located on the northeastern section of the study area. This tribe has been the subject of much media hype in the past couple of months. The land which was righfully theirs has been taken over by 'posseiros', farmers who do not own the land, but occupy it and claim it. The Brazilian government is to blame for this problem, for it had moved the Tapirape from its ground and relocated them further north, giving the chance for the ‘posseiros’. The Tapirape, upon returning to their site after an unsatisfactory relocation, were receive with threats and bullets, being forced to camp on the highway for weeks. The result was disease and death of many Tapirape children and elderly. The ‘posseiros’ are to blame for the increased deforestation rates in the region.

Another factor to analyse is the size of the remaining forest patches. The farmers who clear the land for their crops do so in a way that leaves no natural corridors linking the vegetation and thus the animals. Some crop fields have been estimated to have more than 1000 hectares, without a single break. This method of cultivation is the most deteriorating of all, causing problems with the local micro-climate and baring the land of any resilience.

Conclusion

6. Conclusion

The results obtained in this study reveal the sad truth about the way land use and land cover change is happening in the Brazilian Legal Amazon. It is clear that the legislation, which in paper works wonderfully, is not being exercised or enforced. Large plantations, which at times exceed 1000 hectares, should not be tolerated.

This study provides proof that the type of land-use dynamics taking place in northeast Mato Grosso is harmful to the environment. It is a matter for the large producers to realise the harm done to the environment by mega-monocultures, and for the government to effectively monitor such deeds. Simple and effective measures such as the implementation of tree lines dividing large fields and creating a network of corridors would effectively minimise the negative effects of isolation. These tree lines should be composed of native trees and bushes, and should be at least 50 meters wide.

Another very important issue to consider is the return of the land to their righfult owners. The Tapirape tribe has been placed and replaced in many different locations, but their original grounds is where they want to be. The natives do not exploit the land in an unsustainable way. They do not cut down the forest because they know they will die without it. Their identity is slowly being lost, along with millennia of knowledge. Efforts should be made to return these tribes to their original location, and to increase the value o their knowledge and culture.

The use of landscape metrics and remote sensing for the purpose to characterise the land-use dynamics has proven to be effective. It is unfortunate that in this case study the whole landscape (all 25 cells) is in need of remediation. It is not a matter of where to concentrate the remediation efforts, because the whole landscape needs attention.

Nevertheless, it is recommended that a similar study take place, perhaps contemplating the whole of the deforestation arc. This would generate precious information about the type of remediation techniques to be adopted, depending on the type of deforestation.

It is highly recommended that further studies be done utilising basic landscape metrics, like the ones used here. With the numerous and various types of metrics being created, it is important to maintain consistency.

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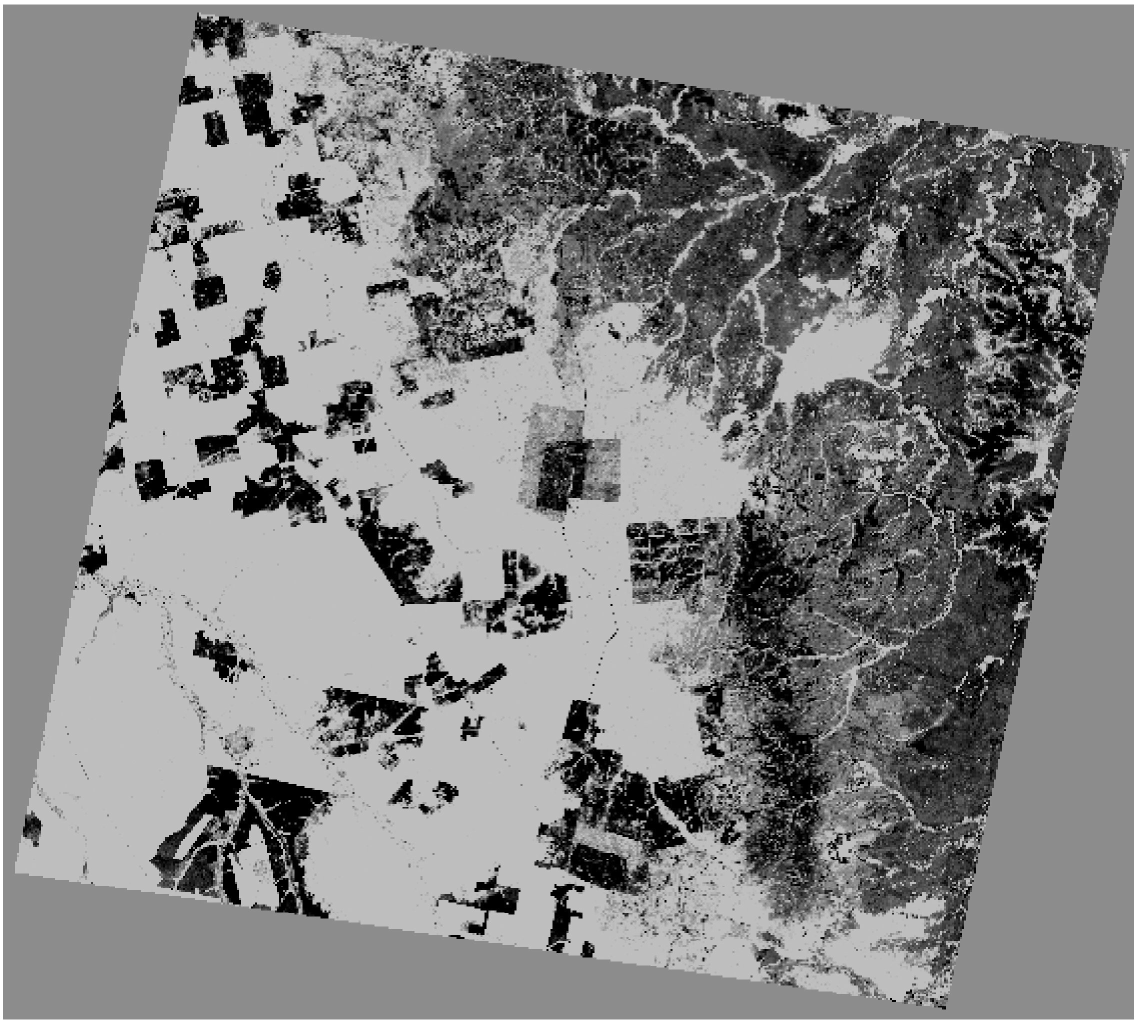
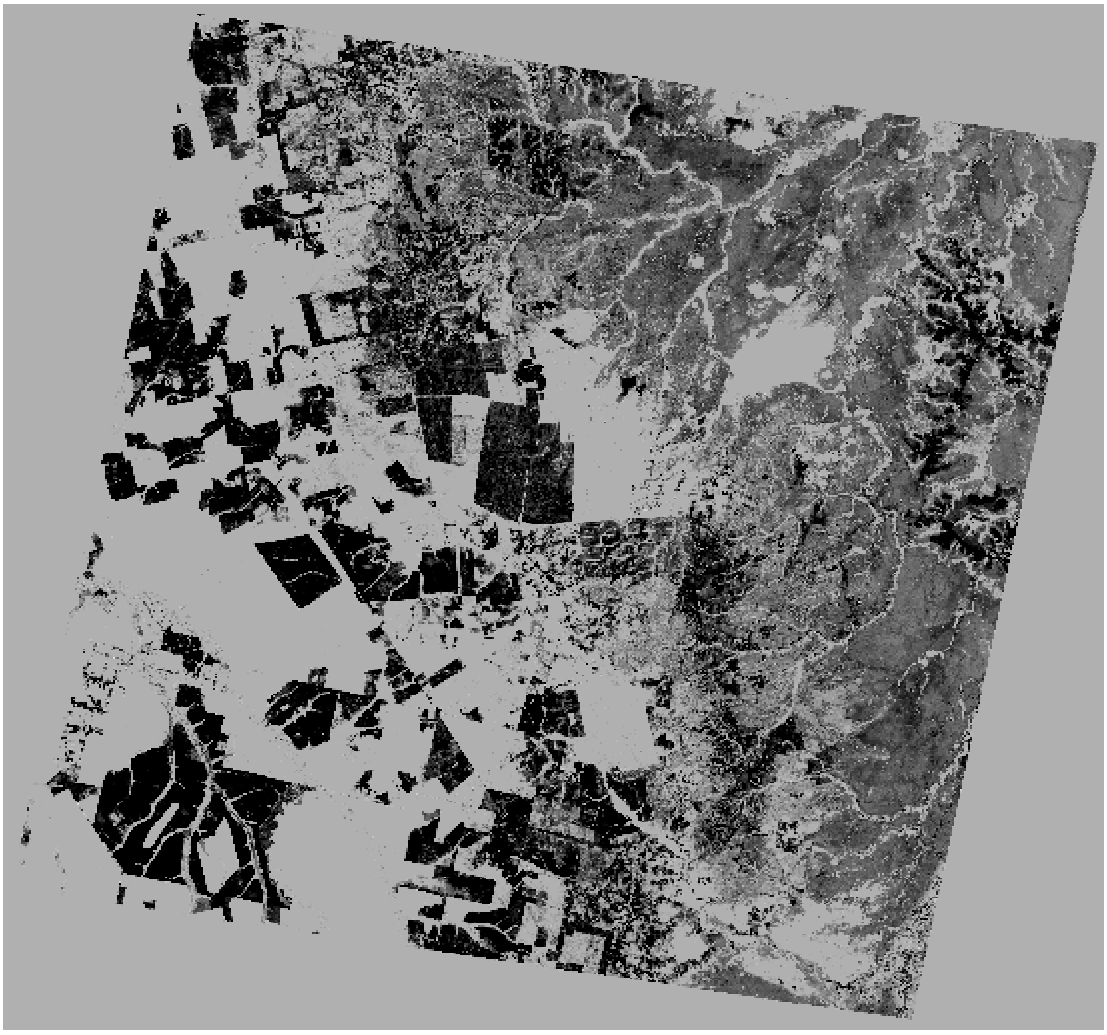
Appendix 1.

TM5 / TM4 Ratio image 1992



Appendix 2.

TM5/TM4 Ratio image 2000

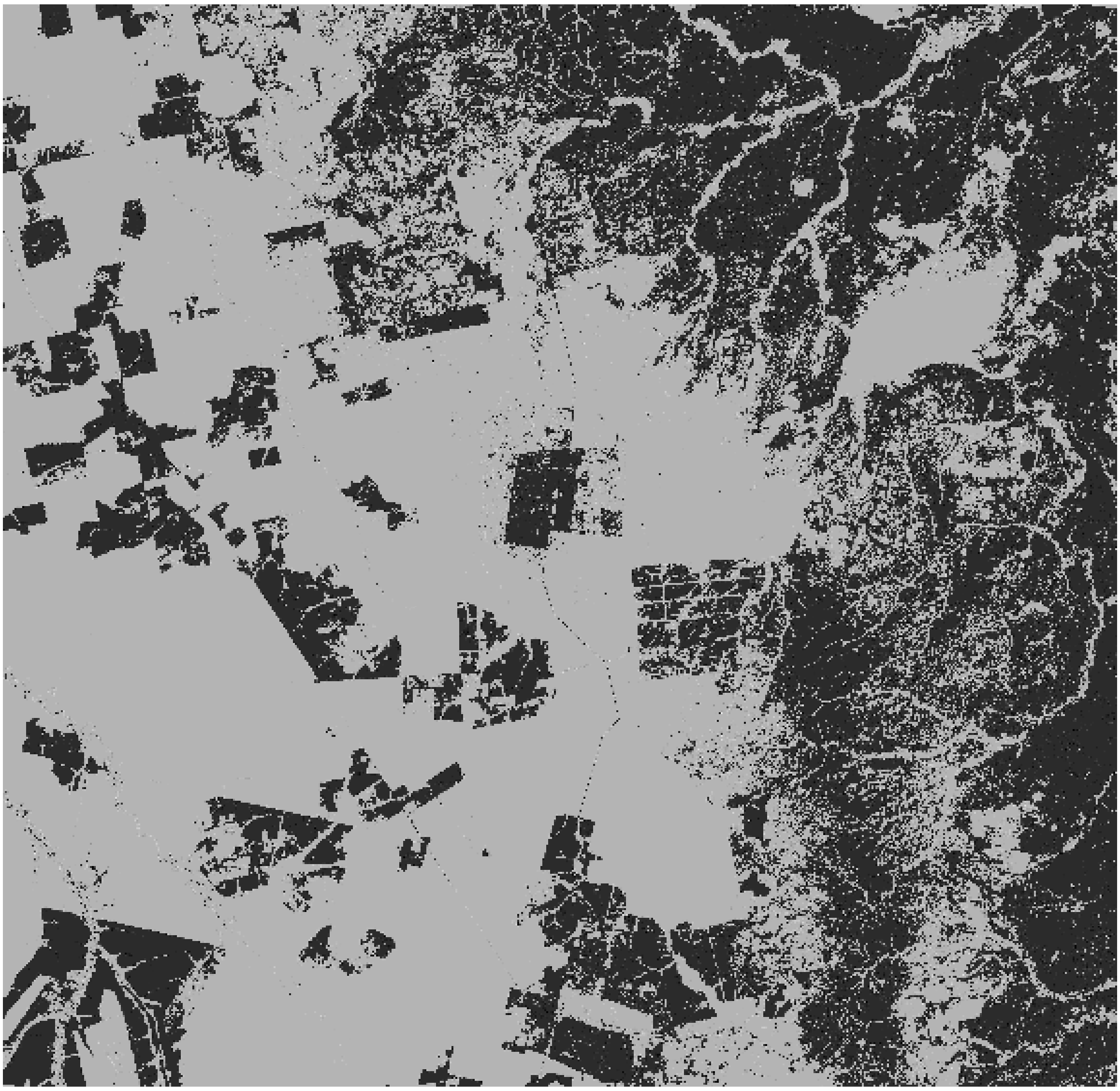


Appendix 3.

TM5/TM4 Ratio image 2003

Appendix 4.

Unsupervised Classification 1992

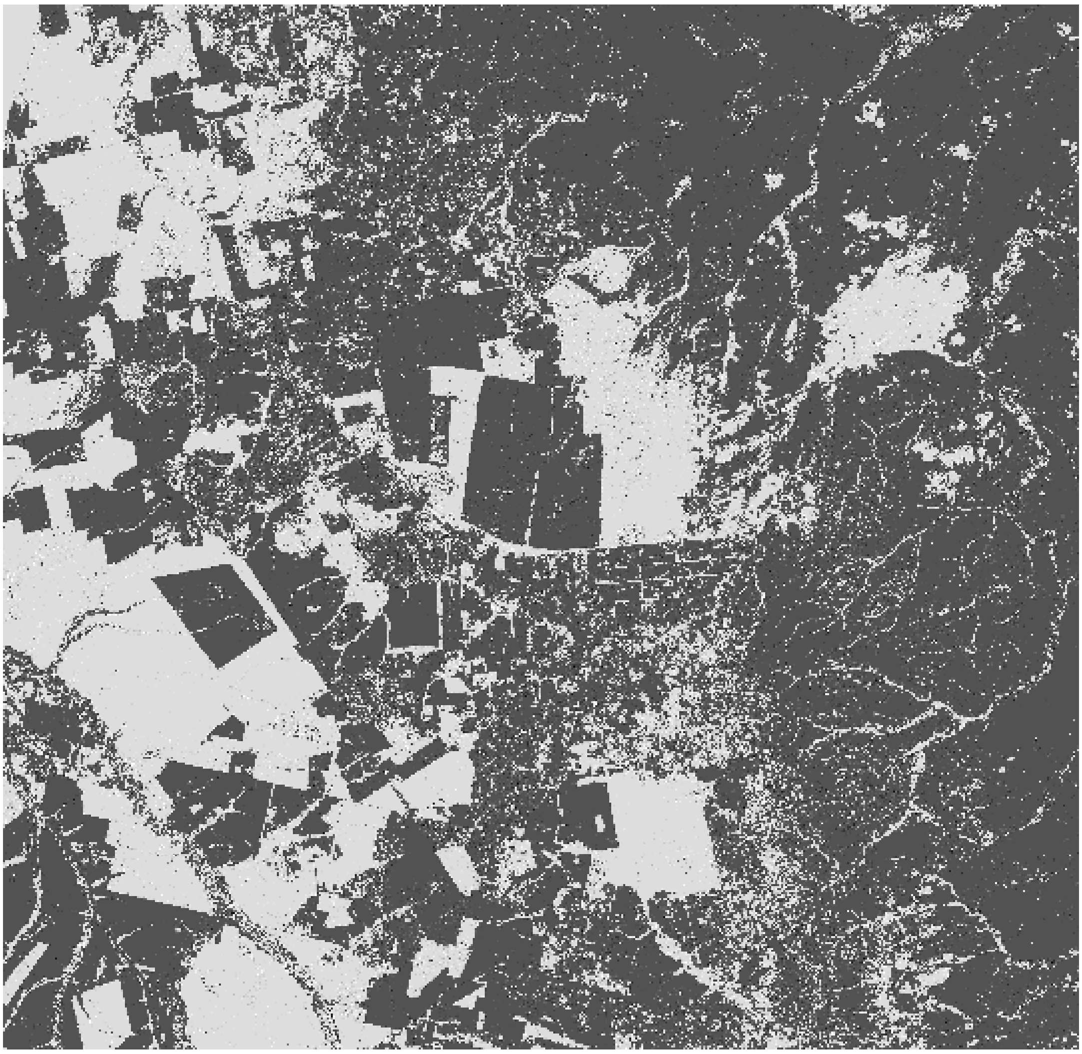


Appendix 5.

Unsupervised Classification 2000

Appendix 6.

Unsupervised Classification 2003



Appendix 7

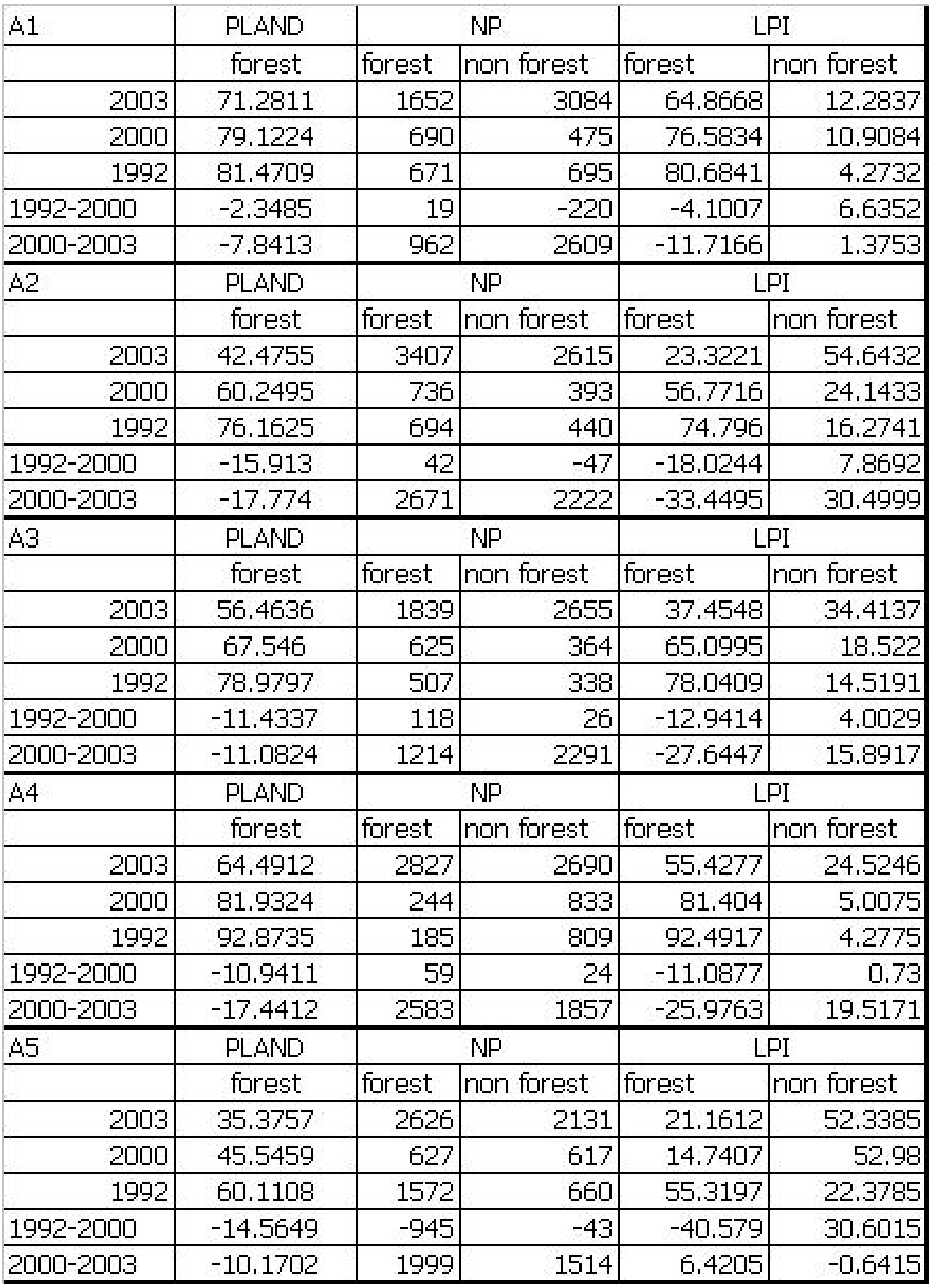
Calculated metrics for the Landscape

Forest	Year		
Metrics	1992	2000	2003
% of Landscape	60.7256	55.5539	30.7821
Patch Density	0.0635	0.0647	0.0822
Largest Patch Index	55.0212	50.0565	9.7431
Landscape Shape Index	34.4893	43.8025	41.0814

Non Forest	Year		
Metrics	1992	2000	2003
% of Landscape	39.2744	44.4461	69.2175
Patch Density	0.0368	0.053	0.0136
Largest Patch Index	17.7882	10.429	66.3639
Landscape Shape Index	42.771	49.0549	28.1403

Appendix 8.

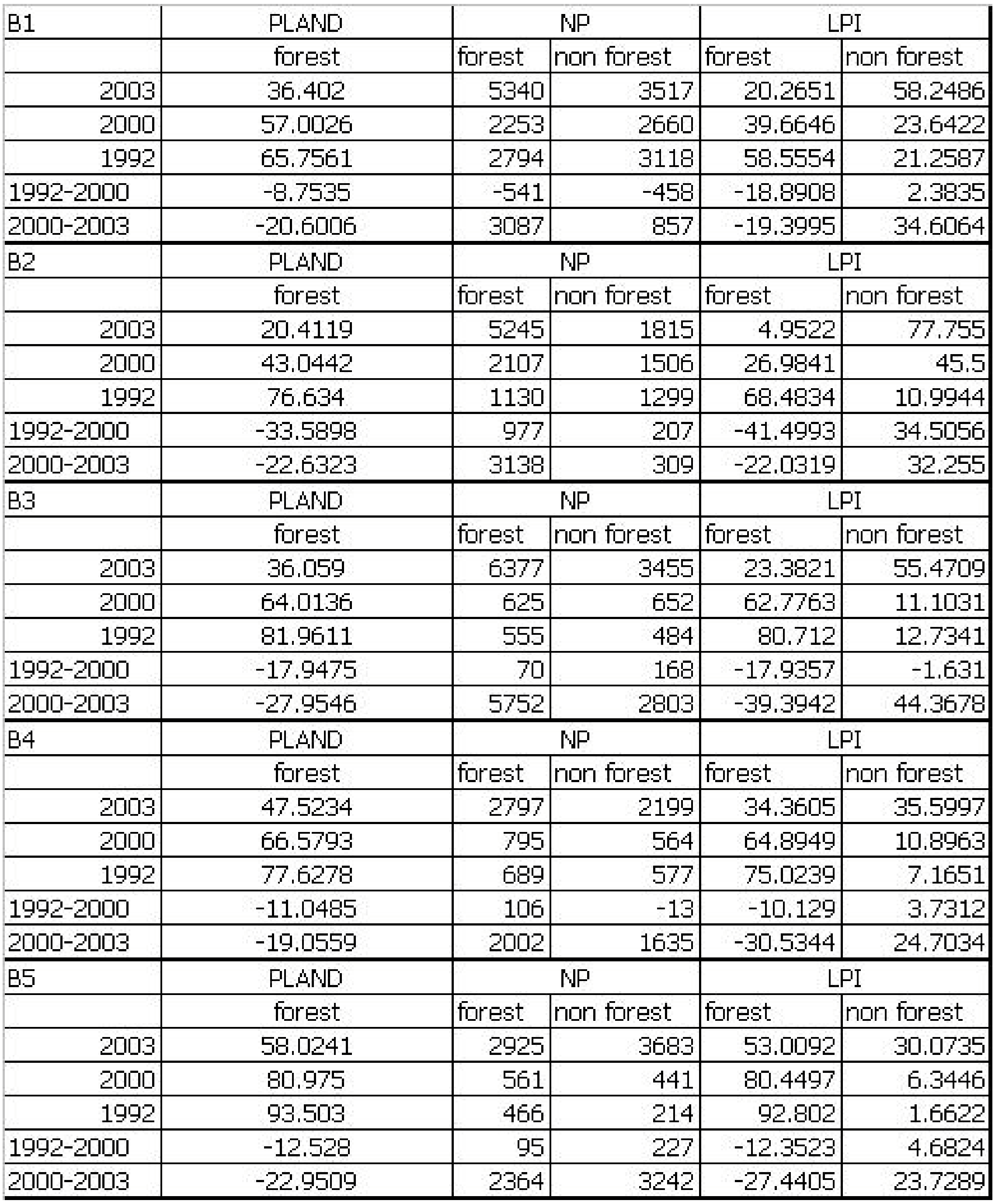
Calculated metrics for 25 cells Column ‘A’



A1	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	71.2811	1652	3084	64.8668	12.2837
2000	79.1224	690	475	76.5834	10.9084
1992	81.4709	671	695	80.6841	4.2732
1992-2000	-2.3485	19	-220	-4.1007	6.6352
2000-2003	-7.8413	962	2609	-11.7166	1.3753
A2	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	42.4755	3407	2615	23.3221	54.6432
2000	60.2495	736	393	56.7716	24.1433
1992	76.1625	694	440	74.796	16.2741
1992-2000	-15.913	42	-47	-18.0244	7.8692
2000-2003	-17.774	2671	2222	-33.4495	30.4999
A3	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	56.4636	1839	2655	37.4548	34.4137
2000	67.546	625	364	65.0995	18.522
1992	78.9797	507	338	78.0409	14.5191
1992-2000	-11.4337	118	26	-12.9414	4.0029
2000-2003	-11.0824	1214	2291	-27.6447	15.8917
A4	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	64.4912	2827	2690	55.4277	24.5246
2000	81.9324	244	833	81.404	5.0075
1992	92.8735	185	809	92.4917	4.2775
1992-2000	-10.9411	59	24	-11.0877	0.73
2000-2003	-17.4412	2583	1857	-25.9763	19.5171
A5	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	35.3757	2626	2131	21.1612	52.3385
2000	45.5459	627	617	14.7407	52.98
1992	60.1108	1572	660	55.3197	22.3785
1992-2000	-14.5649	-945	-43	-40.579	30.6015
2000-2003	-10.1702	1999	1514	6.4205	-0.6415

Appendix 9.

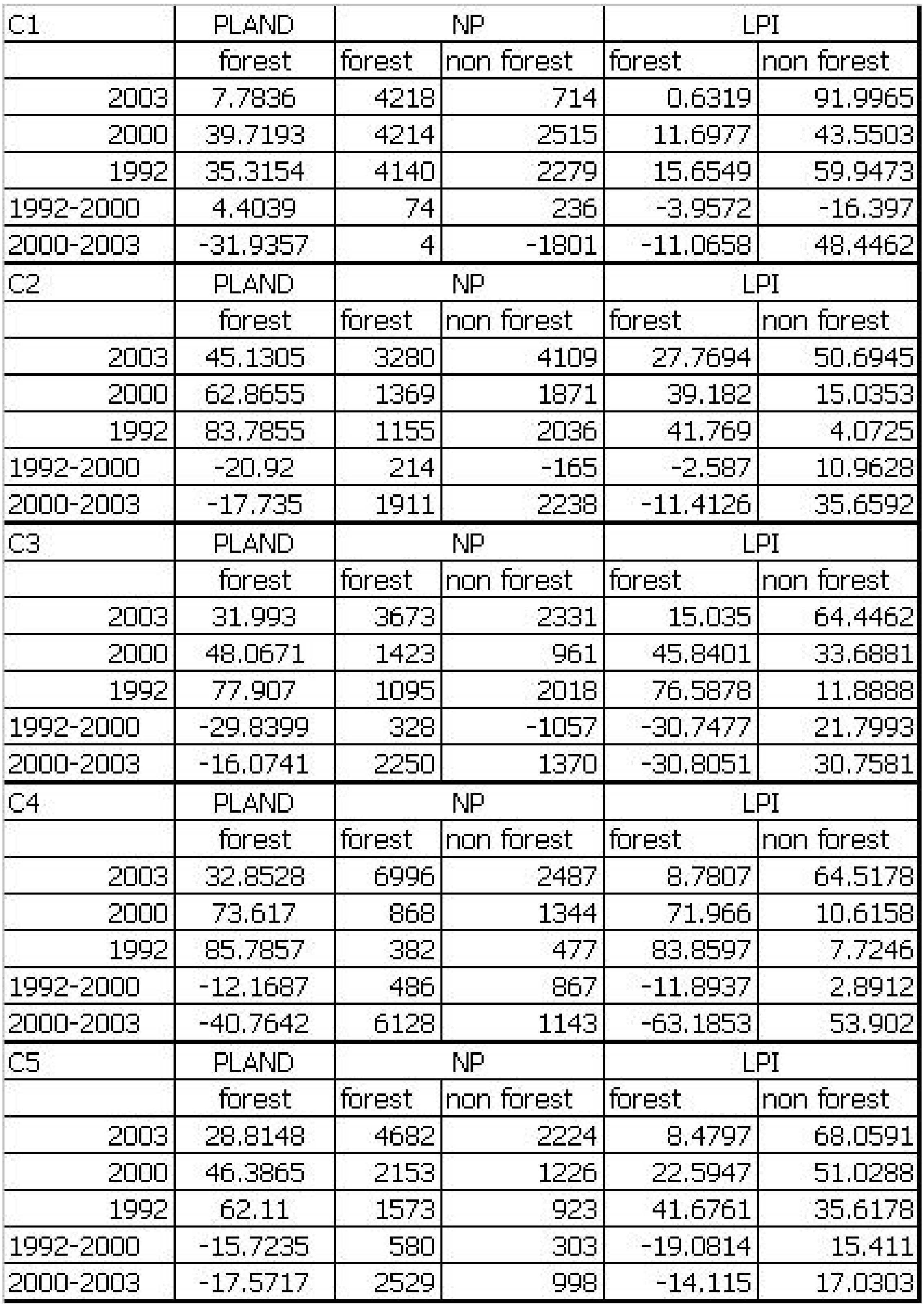
Calculated metrics for 25 cells Column ‘B’



B1	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	36.402	5340	3517	20.2651	58.2486
2000	57.0026	2253	2660	39.6646	23.6422
1992	65.7561	2794	3118	58.5554	21.2587
1992-2000	-8.7535	-541	-458	-18.8908	2.3835
2000-2003	-20.6006	3087	857	-19.3995	34.6064
B2	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	20.4119	5245	1815	4.9522	77.755
2000	43.0442	2107	1506	26.9841	45.5
1992	76.634	1130	1299	68.4834	10.9944
1992-2000	-33.5898	977	207	-41.4993	34.5056
2000-2003	-22.6323	3138	309	-22.0319	32.255
B3	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	36.059	6377	3455	23.3821	55.4709
2000	64.0136	625	652	62.7763	11.1031
1992	81.9611	555	484	80.712	12.7341
1992-2000	-17.9475	70	168	-17.9357	-1.631
2000-2003	-27.9546	5752	2803	-39.3942	44.3678
B4	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	47.5234	2797	2199	34.3605	35.5997
2000	66.5793	795	564	64.8949	10.8963
1992	77.6278	689	577	75.0239	7.1651
1992-2000	-11.0485	106	-13	-10.129	3.7312
2000-2003	-19.0559	2002	1635	-30.5344	24.7034
B5	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	58.0241	2925	3683	53.0092	30.0735
2000	80.975	561	441	80.4497	6.3446
1992	93.503	466	214	92.802	1.6622
1992-2000	-12.528	95	227	-12.3523	4.6824
2000-2003	-22.9509	2364	3242	-27.4405	23.7289

Appendix 10.

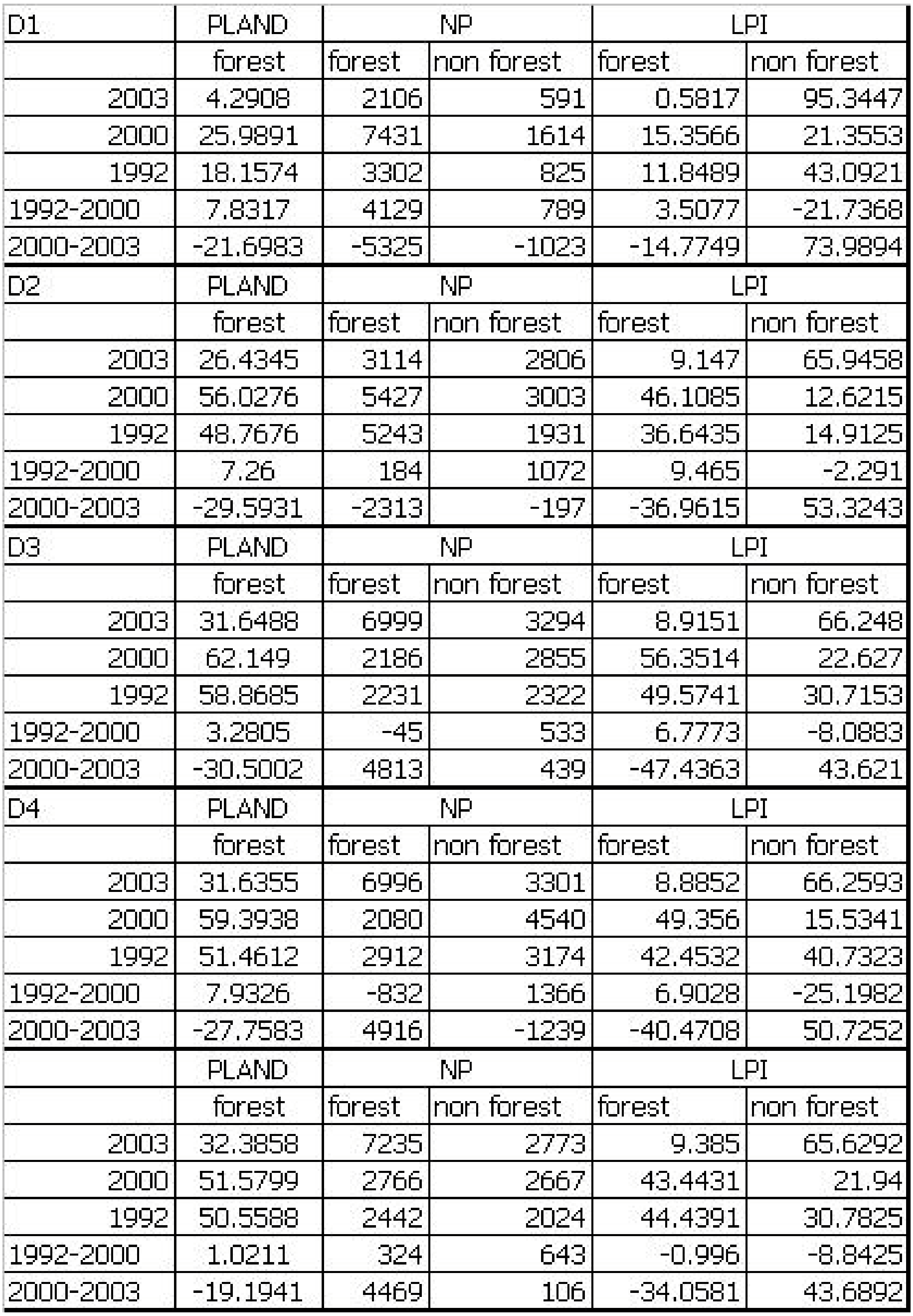
Calculated metrics for 25 cells Column ‘C’



C1	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	7.7836	4218	714	0.6319	91.9965
2000	39.7193	4214	2515	11.6977	43.5503
1992	35.3154	4140	2279	15.6549	59.9473
1992-2000	4.4039	74	236	-3.9572	-16.397
2000-2003	-31.9357	4	-1801	-11.0658	48.4462
C2	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	45.1305	3280	4109	27.7694	50.6945
2000	62.8655	1369	1871	39.182	15.0353
1992	83.7855	1155	2036	41.769	4.0725
1992-2000	-20.92	214	-165	-2.587	10.9628
2000-2003	-17.735	1911	2238	-11.4126	35.6592
C3	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	31.993	3673	2331	15.035	64.4462
2000	48.0671	1423	961	45.8401	33.6881
1992	77.907	1095	2018	76.5878	11.8888
1992-2000	-29.8399	328	-1057	-30.7477	21.7993
2000-2003	-16.0741	2250	1370	-30.8051	30.7581
C4	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	32.8528	6996	2487	8.7807	64.5178
2000	73.617	868	1344	71.966	10.6158
1992	85.7857	382	477	83.8597	7.7246
1992-2000	-12.1687	486	867	-11.8937	2.8912
2000-2003	-40.7642	6128	1143	-63.1853	53.902
C5	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	28.8148	4682	2224	8.4797	68.0591
2000	46.3865	2153	1226	22.5947	51.0288
1992	62.11	1573	923	41.6761	35.6178
1992-2000	-15.7235	580	303	-19.0814	15.411
2000-2003	-17.5717	2529	998	-14.115	17.0303

Appendix 11.

Calculated metrics for 25 cells Column ‘D’



D1	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	4.2908	2106	591	0.5817	95.3447
2000	25.9891	7431	1614	15.3566	21.3553
1992	18.1574	3302	825	11.8489	43.0921
1992-2000	7.8317	4129	789	3.5077	-21.7368
2000-2003	-21.6983	-5325	-1023	-14.7749	73.9894

D2	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	26.4345	3114	2806	9.147	65.9458
2000	56.0276	5427	3003	46.1085	12.6215
1992	48.7676	5243	1931	36.6435	14.9125
1992-2000	7.26	184	1072	9.465	-2.291
2000-2003	-29.5931	-2313	-197	-36.9615	53.3243

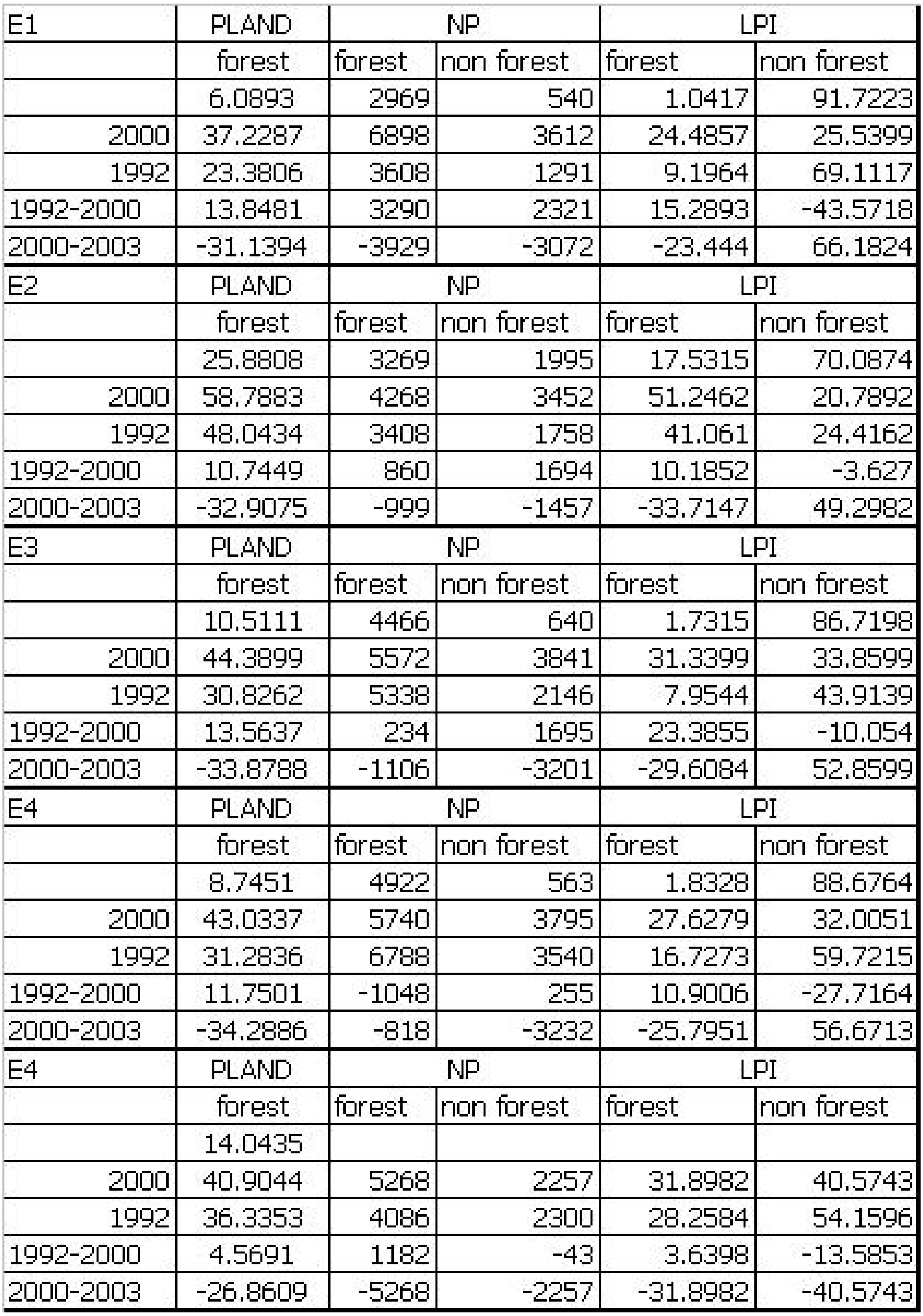
D3	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	31.6488	6999	3294	8.9151	66.248
2000	62.149	2186	2855	56.3514	22.627
1992	58.8685	2231	2322	49.5741	30.7153
1992-2000	3.2805	-45	533	6.7773	-8.0883
2000-2003	-30.5002	4813	439	-47.4363	43.621

D4	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	31.6355	6996	3301	8.8852	66.2593
2000	59.3938	2080	4540	49.356	15.5341
1992	51.4612	2912	3174	42.4532	40.7323
1992-2000	7.9326	-832	1366	6.9028	-25.1982
2000-2003	-27.7583	4916	-1239	-40.4708	50.7252

	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
2003	32.3858	7235	2773	9.385	65.6292
2000	51.5799	2766	2667	43.4431	21.94
1992	50.5588	2442	2024	44.4391	30.7825
1992-2000	1.0211	324	643	-0.996	-8.8425
2000-2003	-19.1941	4469	106	-34.0581	43.6892

Appendix 12.

Calculated metrics for 25 cells Column ‘E’



E1	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
	6.0893	2969	540	1.0417	91.7223
2000	37.2287	6898	3612	24.4857	25.5399
1992	23.3806	3608	1291	9.1964	69.1117
1992-2000	13.8481	3290	2321	15.2893	-43.5718
2000-2003	-31.1394	-3929	-3072	-23.444	66.1824
E2	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
	25.8808	3269	1995	17.5315	70.0874
2000	58.7883	4268	3452	51.2462	20.7892
1992	48.0434	3408	1758	41.061	24.4162
1992-2000	10.7449	860	1694	10.1852	-3.627
2000-2003	-32.9075	-999	-1457	-33.7147	49.2982
E3	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
	10.5111	4466	640	1.7315	86.7198
2000	44.3899	5572	3841	31.3399	33.8599
1992	30.8262	5338	2146	7.9544	43.9139
1992-2000	13.5637	234	1695	23.3855	-10.054
2000-2003	-33.8788	-1106	-3201	-29.6084	52.8599
E4	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
	8.7451	4922	563	1.8328	88.6764
2000	43.0337	5740	3795	27.6279	32.0051
1992	31.2836	6788	3540	16.7273	59.7215
1992-2000	11.7501	-1048	255	10.9006	-27.7164
2000-2003	-34.2886	-818	-3232	-25.7951	56.6713
E4	PLAND	NP		LPI	
	forest	forest	non forest	forest	non forest
	14.0435				
2000	40.9044	5268	2257	31.8982	40.5743
1992	36.3353	4086	2300	28.2584	54.1596
1992-2000	4.5691	1182	-43	3.6398	-13.5853
2000-2003	-26.8609	-5268	-2257	-31.8982	-40.5743