1 Background and general introduction

1.1 Problem statement

This thesis focuses on tree assessment, using tree cover as as a variable. In tree resource assessment, tree cover is one of the variables of greater significance for politicians and decision makers and has become a key issue in both national and international environmental and development policies. International agencies, i.e. the World Bank, the International Monetary Fund and other donors, employ this information as one of the measurable indicators for sustainable management of natural resources.

To assess this variable, metrics or indices are commonly used to quantify or to describe a specific situation. One of the most noteworthy indices is tree cover percentage, commonly used and related to different ecological and economical relevance, to be discussed in this study. Others aspects frequently evaluated are the composition, configuration and shape of tree cover patches.

However, the aspect called "tree cover relative spatial position in the landscape" introduced in this work has not been taken into account in tree cover assessment. Although this aspect has been craving analysis for a while now, it was only in the last couple of years that scientific literature (Hargis *et al.* 1998, Morales *et al.* 2005) took on the challenge of considering this concept. Nevertheless, to date there is no literature or concept to be found.

The magnitude of this new aspect becomes more evident when tree cover is assessed in extremely fragmented landscapes with a small group of trees, or even in only a single specimen. This is especially meaningful for both the economical and ecological aspect of our analyses and may be useful in the different geographical levels of tree cover assessment, i.e. regions, countries, trees in crops, pasture, farms, urban areas, or even in secluded areas such as a parking lots or in recreational areas in a city.

The uniqueness and, therefore, the academic significance of this thesis resided not only in the development of the concept of *tree cover relative spatial position* but also in the approach to assess it in some open areas of Costa Rica by developing and formulating a new procedure to detect and extract tree cover information from scanned panchromatic/color aerial photographs.

1.2 The study region: Costa Rica

The topic of tree cover in open areas - also called Trees Outside the Forest (TOF) (all "*trees on land not defined as forest and others wooded land*" FAO 1998) - in Costa Rica has taken on a particular relevance, as some publications reveal intense timber harvesting practices of trees in pasture land. However, it has not been sufficiently monitored (Campos *et al*. 2001, Flores 2003, MINAE 2001).

Kleinn *et al.* (2002) present an overview of the various forest assessment studies carried out in Costa Rica throughout the last 60 years. However the total estimation of tree cover, including the tree resources outside the forest, has not played a visible role in their assessments.

One of the most recent tree cover assessment studies in Costa Rica (Azofeifa *et al*. 2001, Kleinn *et al.* 2005) focuses entirely on forest. In the case of Azofeifa *et al.* (2001), coarse information (Landsat TM) was used for the estimations, where the minimal mapping area was 3 Ha. Kleinn *et al.* (2005) present a study based in aerial photographs and field work inventory. This study provided, for the first time in Costa Rica, information about the number of trees, volume, species of tree in and outside the forest in Costa Rica, but tree cover estimation outside the forest was again not included.

Indubitably, a clear definition of TOF seems to be a difficult task altogether, since one has to establish the meaning of forest, which is a relatively dynamic term and depends highly on differing points of view, further complicating the possibility of defining a TOF. Today's TOF may become a forest tomorrow (it will only take so much as a change in the definition of a forest), which is exactly why this work focuses on trees, analyzing single trees or groups of trees without, at least at first, distinguishing between the concepts of forest and TOF.

Moreover, according to Kleinn and Morales (2001), there is an information gap regarding the presence, spatial distribution, type and quality of TOF, as well as the temporal changes of its resource, particularly for larger areas. It is also known that these resources provide us with different ecological and economical aspects, such as the conservation of biodiversity, soil erosion control, carbon sequestration, wood, firewood, living fence post, nitrogen fixation. (Harvey and Haber 1999, Schellas and Greenberg 1996, Franke *et al*. 2001, Souza de Abreu 2002, Lang *et al*. 2003, Betancourt *et al*. 2003, Harvey *et al*. 2003, Current et al. 1995). This makes it even more necessary to integrate this resource in tree cover assessment.

There are numerous other reasons for employing Costa Rica as a geographic unit for tree cover assessment:

- Costa Rica had one of the the highest deforestation rates in the world, largely due to the expansion of the agricultural frontier (mainly pasture land) into forested areas (Quesada-Mateo 1990, de Camino *et al*. 2000).

- The deforestation rate between 1986 and 1992 was approximately 4 % per year (Sanchez-Azofeifa *et al.* 2001). This process has increased forest fragmentation (Sanchez-Azofeifa *et al.* 2001).

- According to the FAOSTAT database, in 2004 Costa Rica had 45.8% of the land under permanent pasture. Official numbers for 1988 (SEPSA CNP 1988) show that 48% of the national territory of 50,620 km^2 has been dedicated to animal production.

- In the 1980s, however, Structural Adjustment Programs (SAPs) introduced by the World Bank reduced the profitability of agriculture and cattle ranching in marginal forest lands. SAPs, along with Costa Rican policies that created special conservation areas and promoted reforestation and forest management, have significantly reduced rates of deforestation (Watson *et al.* 1998).

Another vital reason for selecting Costa Rica as the geographic unit for this project is the scientific work of Kleinn and Morales on trees outside the forest assessment in Central America, carried out in CATIE, Costa Rica for several years. The projects "Trees Resources Outside the Forest" and FRAGMENT, funded by the European Commission (project No ERBI-C18T980-323 and ICA4-CT2001-10099 respectively), inspired publications such as Morales and Kleinn (2002), Morales and Kleinn (2001), Kleinn and Morales (2002), Kleinn (2000), Herrera (2003) and others. These projects have prompted some of the basic research questions of this thesis.

1.3 Research objectives

The main objective of this project is to introduce the concept of tree cover relative spatial position in tree cover assessment, as well as to identify ways of assessing it.

The thesis also concentrates on the process of characterizing tree cover in open areas in Costa Rica and analyzing dynamics over time. Throughout this process, a procedure for extracting tree cover information from scanned panchromatic and color aerial photographs in Costa Rica will evolve.

This study also compiles important information about tree cover assessment. It outlines its conceptualization and relevance, indicating future developments as well.

1.4 Structure of the dissertation

This study consists of three closely related papers, each of them with a specific topic. Each paper is organized as one of three major chapters.

Chapter 2 presents a discussion on the definition of tree cover and assessment methods, as well as approaches and needs for the future. As an illustration, a case study of tree cover changes in Costa Rican pasture land is presented, showing the dynamics and characterization of tree cover.

This chapter explains the need to find an index or metric in order to analyze the relative spatial position of the tree cover.

Chapter 3 focuses on the concept of tree cover relative spatial position, how it can be explained, and why it is crucial to assess it, while proposing at the same time an approach to assess it.

In Chapter 4, the proposed approach to assess tree cover relative spatial distribution is tested using data from open areas in Costa Rica. In a second more extensive case study, the focus is placed on landscape in general, as well as patches of forest, and the sample is distributed around the country. Three different time periods are used for this analysis.

In this chapter, tree cover in open areas of Costa Rica is portrayed, ensuing a discussion on the dynamic change over a period of time. In order to carry out this more elaborate case study, a special procedure for tree cover detection in color and panchromatic aerial photographs was developed.

2 Tree cover assessment: the concept

2.1 Introduction

Tree cover assessment is one of the main areas of interest in the natural resource assessment process and has become a key issue in national and international environmental and development politics. International agencies, i.e. the World Bank, the International Monetary Fund, the United Nations and other donors, use this information as one of the measurable indicators for sustainable management of natural resources.

Tree cover assessment also plays a particularly meaningful role in many international agreements, such as the Agenda 21, the Forestry Principles and the conventions on climate change, desertification and biological diversity (Lund and Boley 1995).

In the last years the significance of tree cover mapping has particularly grown from the need to quantify global woody biomass (Hansen *et al*. 2002 cited by Schwarz and Zimmermann 2005). Other studies also show the magnitude of tree cover estimation in different fields such as:

- Biodiversity: High values of tree cover areas relate to more vegetation or other organisms' diversity (woody and epiphytic plants which grow under the trees canopy -Otero *et al.*1999, Janzen 1988, Hietz-Seifert *et al.* 1996-, birds' presence -Bronstein and Hoffman 1987, Lang 2003).

- Production: Dodd et al. 1972, concluded that there is a sufficiently close relationship between herbage production and crown cover in coniferous stands. They suggest that this relation may be useful in wildlife and wildlife-cattle management on forested rangeland. Betancourt *et al.* (2003) found that tree cover increases milk production during the dry season when looking at dairy farms in Nicaragua.

- Hydrology: A mature deciduous forest covered in catchments reduces streamflow compared to a clear-cut area (Burt and Swank 2002).

- **Soils conservation and watershed management**: Wickham *et al.* (2002) carried out a survey of numerous field studies that showed that nitrogen and phosphorous export coefficients are significantly different across forest, agriculture, and urban land-cover types. They concluded that when non-forest cover is in the 20 to 30 percent range, there is a 10 percent or greater chance of N or P nutrient loads being equivalent to the median values of predominantly agricultural or urban watershed.

- Urban planning: Vegetation canopies cool microclimates both directly, by shading of the ground surface, and indirectly, by the transpiration of water through leaves (Lee 1978). Air temperature differences of approximately 2 to 4°C have been observed for urban neighborhoods of contrasting tree cover, which means an average of approximately 1°C for every 10% canopy cover (Huang *et al.* 1987).

Tree cover assessment also provides common information, such as the tree cover percentage of an area, region or country. This simple figure of high political and economical meaning, is commonly used in forestry and also holds wide interest in other scientific fields (Kleinn *et al.* 2002). But there are also others aspects which make tree cover assessment more complex: such as composition, configuration and shape of tree cover patches.

In general terms, tree cover appears easy to assess, but it requires special attention and techniques to get reliable results. Approaches and tools are constantly being developed.

This chapter deals with the meaning of tree cover and discusses some methodologies or approaches to make its assessment, including approaches and needs for the future. A case study of tree cover changes in pasture land in Costa Rica is introduced as an illustration.

2.2 What is tree cover?

Spurr (1960) defines tree cover as "the proportion per unit area of the ground covered by the vertical projection on to it of the overall tree crowns".

Most of the studies about tree cover are generally associated with forest ("*forest assessment"*) and it is normally expressed in percentage. Usually, two different concepts are found: "forest area" (*land use*) and "forest cover" (*cover area*). Land use describes the way land is occupied or utilized and land cover is the observed physical and biological cover of the land surface. In the case of tree cover assessment, the focus is primary in terms of crown cover area of trees, without looking in a first stage at the land use where trees are.

Tree crown closure or crown density is another concept similar to tree cover. In fact, some authors make reference to both models being the same thing, but depending on the context in which these concepts are used, at least one difference is observed: crown closure is the percentage of ground covered by a vertical projection of the outermost perimeter of the crowns in a *stand*. Crown closure refers only to those areas included in a forest, forest plantation or patch of forest of our interest and is used as a measurement for stand density and competition.

Crown closure may be measured through aerial photographs or other remote sensor imagery. It is also very useful to classify one stand in different types of forest according to pre-defined crown closure per patch. In some definitions of forest, tree crown closure works as an significant criterion to define whether a group of trees in a specific area form a forest or not (FAO 1998, European Commission 1997, Kleinn 2001).

2.3 How to assess tree cover?

The use of land survey, photogrammetry and remote sensing are ways to assess tree cover.

Land survey determines tree cover by measuring the crown sectional area of all isolated or groups of trees which is then divided by the total area of the study and is expressed as a percentage. However, this method is usually difficult to apply in large areas, so the method of sampling must be used. Inoue (1999) summarizes two methods which may be applied in the field in the case of sampling: line intersect sampling and point sampling, Williams *et al*. (2003), described a technique called "morphing", and compared it with point and line intersect sampling. He found that for the populations studied in his research, the bias of tree cover estimator derived from the morphing technique was negligible. He also reported that the estimator based on line intersect sampling is design-unbiased, but that it generally had a much larger variance than the one based on the morphing technique. The point sampling method consistently had the highest variance. Nevetheless, these methods tend to overestimate tree cover when compared with the estimations made through remote sensing, because the tree crowns overlap.

Kleinn *et al*. (2002) and Spurr (1960), assert that tree cover as a criterion, for instance, is difficult to estimate in the field and that it may be more easily done by using air photos of appropriate scale.

According to Huss (1984), in the case of using photogrammetry, tree cover is estimated through aerial photographs, by photogrammetric or visual use: photogrammetric crown mapping and using planimeters, visual estimates, comparison scales, point sampling and angle counting sampling. To get a better idea of these techniques, see Hildebrand (1996), Howard (1991), Spurr (1960), Huss (1984).

One must mention that tall trees, polar–facing slopes, short focal lenses, infrared photographs, early morning or late afternoon photography, areas towards the periphery of the photographs and small-scale photographs lead the photo interpreter to overestimate tree cover. Spurr (1960) also describes that the precision of area measurement depends upon (1) the accuracy of the photograph or map being measured and (2) the method of measurement adopted. If area measurements are made directly by using photographs, errors may arise owing to variations in scale and slope.

In the case of remote sensing, tree cover is assessed by analyzing changes in the amount and properties of the electromagnetic radiation recorded in the sensor, using different technical procedures. Other types of force fields, such as sound waves, may be used instead of electromagnetic radiation. However, the majority of remotely sensed data collected for Earth resource applications are the result of sensors that record electromagnetic energy (Jensen 1996).

Nowadays, the most popular approach to assess tree cover is by employing image products, since they are more available, more cost-effective and more precise.

Spatial resolution and radiometric resolution of the sensor are factors of high importance for assessing tree cover from remote sensing imagery.

Spatial resolution is a measure of the smallest angular or linear separation between two objects resolved by the sensor (Jensen 1996). The information gathered by the sensor is split into 'pixels' (or picture elements). A pixel is the smallest unit of an image, which contains color data related to what is found within that definite area. Some satellite platforms provide high-resolution images with 0.6-m pixel sizes (e.g. Quickbird, IKONOS), while other satellites provide images with a coarse resolution of 30 m (e.g. Landsat 7). If the resolution is too low, one may have trouble discriminating object classes, but on the other hand if the resolution is too high, intraclass variability increases, thereby decreasing overall accuracy. A relationship exists between the size of a feature to be identified and the spatial resolution of the remote sensing system.

Radiometric resolution defines the sensitivity of a detector to differences in signal strength as it records the radiant flux reflected or emitted from the terrain or target of interest. It determines the number of barely discriminable signal levels. Consequently, it may be significant in order to identify scene objects (Jensen 1996).

There are at least two main approaches documented to assess tree cover by remote sensing. The first one is mapping all possible tree crowns in the study area, making a detailed interpretation of each tree cover patch where, naturally, the minimum mapping object depends of the resolution of the remote sensors used. A layer with the pixels classified into "tree cover" and "non tree cover" (1 and 0) is produced (see for illustration Koukal and Schneider 2003).

In the second one, the goal is to compose a map of "*continuous fields of tree cover or continuous tree cover fractions*" (DeFries *et al.* 1999, Schwarz and Zimmermann 2005), in which a fractioned estimation of tree cover percent per pixel is made by using different techniques such as:

Land use/tree cover relationship: A relationship between land use classes and a predefined tree cover percentage per land use is used (for example: residential areas= 15%, fruit yards 30%, etc. (Schwarz and Zimmermann 2005).

Fractions of tree cover per pixel: A previous tree cover map (as in approach 1) is used, where a moving sampling window of size "*X*" is used across the area to calculate tree cover percentage per pixel (for more details and different techniques, see for example: Schwarz and Zimmermann 2005, Bai *et al.* 2005, DeFries *et al.* 1999, Hansen and DeFries 2004).

This second approach is commonly applied with coarse resolution imagery, where small objects can not be easily detected and where the correlation between land use and tree cover would be easier. However, some authors like Bai *et al.* (2005) have also used it with high resolution imagery. With this second approach, it is important to keep in mind that land use is not always adequately correlated to tree cover presence (Koukal and Schneider 2003), and that the use of a moving sampling window of size "*X*", would cause some setbacks, since the size of the moving sampling window has a general effect on the estimation of the tree cover percentage. This supposition is also valid for field estimations and air photo interpretation, where sampling approaches are used (see for illustration Kleinn 2001).

2.4 Where does the concept of tree cover come from?

It is difficult to determine where the concept of tree cover assessment comes from and when it was first mentioned. As pointed out before, this term has generally been used in relation to forest assessment, and one may assume that this concept was born from Man's need to make estimations on how much forest there was. It is likely that the first tree cover assessment was done in the field and that air photographs were used later on.

According to Howard (1991) the first known popular interest in the viewing of trees on photographs was in 1838, when Wheatstone demonstrated his reflecting mirror stereoscope. Forty nine years later, aerial photographs were taken purposively from a balloon near Berlin in order to examine the stand characteristics of beech, spruce and pine woods (Hildebrand 1996).

Spurr (1960) also points out, that prior to World War I, the few foresters interested in photogrammetry confined themselves to its terrestrial aspects. The same author mentions that in Austria, Rudolf Kobsa and Ferdinand Wang wrote articles on this subject in 1892. They were followed by Dr. R. Hugershoff, who began writing in Germany in 1911 and by Hans Dock in Austria in 1913. Thus it was not until after World War I that aerial photography really attracted the interest of foresters or found practical use in forest mapping.