ASSESSING FOREST COVER IN THE UPLANDS OF SOUTHEAST ASIA

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ABSTRACT

Remote sensing data and digital image processing is widespread being used to map tropical rainforest and its changes. The purposes differ from global and regional assessment of forest cover in a global change context to local needs for natural resource planning support. While good accuracies can be obtained using the right methodology (overall accuracy superior of 90 %) for a limited area, the broad worldwide or regional maps may work at the large scale, but will inevitably have a bias at the local scale. Despite these shortcomings, these latter forest classifications are more and more being used as planning support because of their extended coverage and readily availability. The present paper assesses the pertinence of using broad global classifications in a local context in mountain forests in the Ca river basin in northern Vietnam. In order to understand the land-cover and the production system, field studies were conducted and it appeared that there was no or insignificant on-going clear-cutting of the remaining forest and shifting cultivation was important in the area. Settlements varied much in size from less than a hectare to over 10 hectares and the fields were cultivated from one to three years at the time, leaving the soil fallow for a period of a few years up to 20 years. Four broad land cover classifications available for the Ca river basin were compared to determine how well they characterized the land-cover and the production system found. The three broad classification schemes, Pathfinder (Tropical Rainforest Information Center, 1998), FAO (FAO, 2001) and Tropical Ecosystem Environment Observation by Satellite (TREES, 2001) where compared to Tottrup's verified land-cover maps derived from multi-date classification of Landsat ETM data (Tottrup 2002). It was shown that the broad classifications over- and underestimated the forest area with a magnitude in difference and hereby fail to capture the important balance between the agricultural system and the forest. Specifically land-cover classes associated to the exploitation of the forest, the degraded forest, bamboo, shrub, grass and farmland are not allocated consistently to either forest or non-forest. These classes are of primary relevance to local forest management and it is concluded that broad classifications should not be used in a local context without previous verification. The paper includes discussion on how lack of understanding of the production system affects the classification result and equally how unintentional selections of remote sensing data from different periods can have a significant influence on the classification result. It is concluded that using multi-date classifications of Landsat or equivalent high-resolution data provide the necessary high quality information to characterize the forest dynamic.

Keywords: Remote Sensing, Deforestation, Land cover, Tropical forest, Landsat, Shifting cultivation

Introduction

The mountainous area of Southeast Asia is considered one of the most important deforestation and land cover change "hotspots" in the world. Along with the Amazon Basin and the Congo Basin, the forests of Southeast Asia are considered the most vulnerable to deforestation. Land cover change, including deforestation, is considered a very important factor affecting ecological systems (Vitousek 1994). It is often considered environmentally harmful and one of the driving factors behind global climate change. When a mountainous area is deforested it may affect the area's hydrological cycle (Konnick 1999), leading to erosion, flooding, sedimentation, and changes in water quality that negatively impact on downstream agriculture, aquaculture activities, and hydropower generation (Douglas 1999, Lørup et al 1998). When this same area is deforested, the carbon that has been stored in the forest is released into the atmosphere and the area goes from being a carbon sink, to a producer of carbon in the short run, contributing greenhouse gases to the atmosphere (Skole and Tucker 1993, Foody et al. 1996). Furthermore, land cover change is also expected to be the most significant variable affecting biodiversity for next century (Chapin et al. 2000).

Deforestation, and more generally land cover change, can also affect the prospects of economic development and local livelihoods. On the positive side the clearance of forest for agricultural purposes and timber production, among other activities, may help to raise national, local and household incomes. This must however be balanced by the adverse effects caused by reduced supplies of wood for energy and housing, decreased amounts of non-timber forest products, such as fruits, rattan, wildlife and medicinal plants (Lambin 1994), and perhaps rising prices on forest goods. Thus, the published accounts that the mountain areas of Southeast Asia are undergoing widespread deforestation are a cause for ecological, economic and social concerns.

However, are these types of areas really going through a rapid deforestation, or is the structure of the vegetation covering the land, the forest morphology, merely changing overtime? If this is the case, is the change in structure permanent or part of longer-term historical patterns? The FAO defines deforestation as "the transfer of forest land to non-forest uses and includes all land where the forest cover has been stripped and the land converted to such uses as permanent cultivation, shifting cultivation, human settlements, mining, and building of dams" (Rao 1989, Holmgren and Davis 2000). By this definition deforestation means the complete clearing of forest and the permanent change in the land-use so that the forest does not regenerate. A non-permanent change in the land-cover, e.g. in situations where forest land is temporarily cleared and then allowed to regenerate, or where forest is thinned of trees, may be variously thought of as "degradation" (Rao 1989) or, less judgmentally, as a change in forest morphology.

The term "forest" is also open to different interpretations. For example, one definition states that forest is "generally, an ecosystem characterized by a more or less dense and extensive tree cover," and "a plant community predominantly of trees and other woody vegetation, growing more or less closely together," (Ford-Robertson 1971). Another states that it is an "ecosystem with a minimum of 10 percent crown cover of trees and/or bamboos, generally associated with wild flora and fauna and natural soil conditions, and not subject to agricultural practices" (FAO 1999).

Fox et al. (2000) suggests that deforestation, referring to a permanent change in land cover from forest to non-forest, is not taking place to the extent previously suggested for the northern mountain regions of Vietnam. Rather, given the farming systems and logging practices, what is actually happening is that the land-cover is temporarily being cleared of trees and used for active swidden, and the general class of "forest" is quickly regenerating.

Our experience in the Ca River Basin (CRB) seems to support the analysis that the land-cover change that is taking place is not one of "forest" to "non-forest," but rather one of changes in the quality of the broad category of "forest." It appears that the changes taking place are in the amount of area that is found in the "degraded" forest, brush, bamboo, and grass types of land-cover and the movements of areas between these categories, rather than in wholesale movement of areas from "forest" to "non-forest" or the "other land cover" categories.

In order to confidently state that deforestation is going on at a rapid pace in Southeast Asia, it must be shown that forest areas are being permanently converted to other, non-forest, and land-cover types. This requires primarily a good understanding of the relevant production and ecological systems, in order to identify pertinent land cover classes and assess how remotely sensed data can contribute to map the changes. The choices of remote sensing tools and methods have to be sensitive enough and appropriate to distinguish between important forest types and different types of non-forest land-cover. These tools and methods also have to produce results that are consistent over time with repetitive mapping exercises.

The work described in this paper is based on an environmental assessment study in the CRB, an activity within the Resource Policy Support Initiative (REPSI) project (WRI, 2002, Institute of Geography, 2002). Figure 1 shows the geographic location of the study. The objective of this paper is to assess the information contents of different remote sensing forest-mapping approaches relative to the ecosystem and production system complexity in the study area. It is believed that in order to map relevant changes in forest cover, land cover maps should be produced with a high accuracy and with a high temporal frequency.

(INSERT Figure 1 – Location Map)

Since quality information on forest cover in areas like Southeast Asia is scarce or often is collected in a decentralised manner; a number of decision makers are willing to use the coarse and gross forest maps derived from remotely sensed data. These are intended to be used for larger regions or even at the global scale and are easily made available through the Internet or freely distributed on CD ROM. Consequently, a second objective is to assess the quality of these coarse maps for the case of the CRB, both in terms of the actual information, how reliable the map is itself, as well as their capabilities to predict changes in time from a series of maps. It is anticipated the coarse maps may not capture details, but will they be accurate enough to capture the general situation? Furthermore, are the methods applied for the regional or global mapping robust enough to identify significant changes in forest cover in time or are the biases of these maps varying too much over time to be used in a local context? The lessons learned will be relevant for other areas of the Southeast Asia mountain region.

Remote Sensing

Remote sensing of reflected electro-magnetic radiation from the earth's surface has been used intensively to map forests over the past 30 years since 1972 when the first earth resource satellite was launched. The sensor system carried by earth observation satellites is often characterized by three distinctive resolutions. The sensors *spectral resolution* refers to the number and dimensions of specific wavelength intervals recorded by the sensor. *Temporal resolution* refers to the time interval between repetitive recordings of a specific area. *Spatial resolution* refers to the smallest detectable area, by the sensor, on the earth's surface. Spatial resolution is often referred to as the *pixel size* of the image (pixel is short for *picture element*). The choice of sensor system for a specific study (and the methods that are used to interpret the information provided by the sensor) often involves a balance between the specific objectives of the study and the cost and availability of data. The first Landsat instrument was the Multispectral Scanner (MSS) with 79-meter pixels and was followed by the Thematic Mapper (TM) with 30-meter pixels in 1984. The latest Landsat 7 satellite with the Enhanced Thematic

Mapper (ETM+) instrument has a spectral resolution of 7 bands in the visible and near-infrared and mid-infrared parts of the spectrum, the temporal resolution is 16 days and the multispectral spatial resolution is 30 meters and 15 meters for the single pan-chromatic band.

There are two main applications of satellite remote sensing to forest mapping, the first, and most widely used, is the classification of multispectral data from such satellites as Landsat, Spot or Ikonos. The classification is done visually or automatically using digital image processing. The principle in these cases is to characterise the spectral signatures (a unique combination of reflected electro-magnetic radiation in different windows of the visible, near-infrared, and mid-infrared parts of the electromagnetic spectrum) for the land cover or forest classes that should be mapped. There are two commonly used methods for doing this. One is the supervised classification method. This method consists of the use of training areas, which are identified in the field, that are used to derive the spectral signatures prior to the digital image processing software generalising this information for the study area. The other widely used method is the unsupervised classification. This method allows the digital image processing software to initially subdivide any given area into a user-defined number of classes. Next information from fieldwork or from other ancillary data is used to help label the classes and possibly merge (or split) some of them in order to obtain a generalized map of land cover.

The second main application of satellite remote sensing to forest mapping has been developed over the past 20 years using time series data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) to capture the dynamics of changes in vegetation from vegetation index data. The AVHRR instrument has only two bands in the visible and the near infrared part of the spectrum and the spatial and temporal resolution is 1.1 km and 12 hours respectively. This is however sufficient to compute a vegetation index. The vegetation index is a measure of the photosynthetic capacity, and annual and inter-annual variation can be used to identify forest communities with the same photosynthetic dynamic. This approach also needs additional field checking in order to produce a generalised forest or land cover map. To learn more about remote sensing of forests, see Tottrup (2002) and Lambin et al (1997).

Remote Sensing of Tropical Forests

The majority of what is known about land cover in Vietnam comes from one of two sources: periodic land-cover analyses carried out by Vietnam's Forestry Department and/or General Direction of Land Administration, or large area, small scale, analysis of land-cover done by international research projects focusing on tropical forest cover assessments and change. These programs include the Landsat Pathfinder Project (Tropical Rainforest Information Center 1998), the FAO Forest Resource Assessment (2001), and the "Tropical Ecosystem Environment Observation by Satellites" (TREES) program (2001). These programs also often collaborate with institutions within Vietnam, such as the Department of Forestry, in order to carry out their assessments.

Landsat Pathfinder has carried out assessments of forest cover in the tropics on a decadal basis for the 1970s, 1980s, and 1990s. For our study area the most recent assessment was done using 1992 Landsat TM data. The FAO Forest Resource Assessment is also done on a decadal basis and for our study area the most recent assessment was done using AVHRR data from the year 2000. The TREES program is also trying to do decadal analysis of forest cover, although only one has been done to date. For our study area the assessment was done using AVHRR data from 1992/1993.

The government of Vietnam draws on the Department of Forestry's land-cover analyses for many of its planning needs. International non-governmental organizations (NGOs) and multi-lateral organizations working in the fields of development and conservation /

biodiversity rely on either the Forest Department's land-cover assessments, assessments that have already been done by the aforementioned projects, or assessments done by groups using methods similar to those used by the aforementioned projects. The varying land-cover analyses are used to decide on such things as where biodiversity is most threatened, how much deforestation is going on, where conservation priorities should be focussed and what government land use policies should be pursued. The information derived from these analyses is also used to determine changes in land-cover over time and how humans (and their agricultural systems) impact land-cover. All of these analyses rely on remote sensing.

In order to measure world-wide or regional scale tropical deforestation, studies using remotely sensed data, especially NOAA AVHRR and Landsat MSS/TM data have been used. Some of these studies, such as the Landsat Pathfinder Project, the FAO Forest Resource Assessments and TREES, can be viewed as operational forest monitoring systems. In order to assess deforestation rates, the procedures followed in these studies have been to simplify the input classes to just one or only a few broad forest classes. For example, Pathfinder classifies the Landsat imagery into four classes: forest, non-forest, water and clouds (Brunner et al. 1998) and TREES divides land-cover into evergreen forest, seasonal forest and non-forest. The simplified classification scheme is used to compare the classified images from different dates on a pixel by pixel basis. This simplified classification scheme provides the user with high individual scene accuracy and helps maintain the accuracy of the final analysis (Salas et al. unpublished report). In these simplified classification schemes land cover types such as primary forest, secondary forest, bamboo forest, and many combinations of woody brush are usually considered forest, and barren areas, grassland, rock and agriculture are usually considered non-forest.

In addition to the above studies related to the classification of the tropical forest a range of studies have considered the spatial patterns detectable in remotely sensed imagery (e.g. Mertens and Lambin 1997; Brunner et al. 1998, Salas et al. unpublished report). Husson (1995)[1] proposed a typology in which recognizable spatial patterns of non-forest areas are associated with different processes of deforestation. This typology distinguishes between the following patterns: Geometric (large-scale clearings for modern sector activities), Island (peri-urban areas), Corridor (roadside colonization by spontaneous migrants), Diffuse (smallholder, traditional subsistence agriculture), Fishbone (planned resettlements schemes) and Patchy (high population density areas with residual forest patches). The typology is useful for stratifying larger regions into areas characterized by uniform deforestation patterns.

Some studies suggest that the spatial patterns associated with individual clearings can indicate whether the forest has been cleared for agricultural purposes or for logging. These studies suggest that within Southeast Asia, non-forest areas less than 4 hectares are clearings for agricultural purposes, while areas larger than 4 hectares are clear-cut logging areas (Brunner et al. 1998). The Pathfinder forest / non-forest classification has also been used to determine shifting cultivation rotations (Brunner et al. 1999).

Leisz et al. (2001) carried out five land-cover analyses as part of a large study on environmental, social conditions and development trends in five communities in the northern mountain region of Vietnam. One of these studies was in the CRB. In contrast to the methods described above, this land-cover analysis, using Landsat TM imagery from November 1998, is based on a supervised classification of the satellite image using a maximum likelihood classification. Fieldwork was done to collect 200 ground truth points that were used in the classification. At each location where ground truth data was collected, local informants were interviewed regarding the land cover and the history of land use in the area. Of the ground

[1] According to Mertens & Lambin 1997

truth point data, 69 were used to create training sets and 131 were used to assess the accuracy of the final land-cover analysis. This analysis determined that classes of forest, bamboo forest, brush, tall grass, short grass, wet rice fields, and swidden (upland) agriculture fields, could be delineated with a high degree of confidence. The study results showed that 83% of the ground truth reference points were correctly classified. This result suggests that given good ground truthing it is possible to delineate a more complex land-cover map of the study area than the classifications discussed above.

Tottrup (2002) also used a maximum likelihood supervised classification to derive a forest and land-cover map of the upper CRB. Tottrup used multi-date Landsat imagery and pre-classification image smoothing and achieved a higher classification detail and accuracy than Leisz et al. The smoothing of the imagery decreased the variation of the reflective response within the different vegetation types and provided a better training signature for the supervised classification. This was done as per Hill and Foody (1994) who suggest that the differences of spectral responses of tropical forest and land cover classes is more a function of textural differences within vegetation classes than between the classes. Thus, smoothing decreases the "in-class" differences and accentuates the "between-class" differences, providing the analyst with better training sets for carrying out the land-cover classification analysis. Also, Tottrup's use of multi-date imagery significantly improved the classification performance by extending the information content to include information on phenological stages and canopy texture. Tottrup's results suggest that it is possible to accurately classify up to thirteen types of land-cover in the study area: water, rocks, built-up area, wet rice paddy, bare soil, grass, farmland (swidden or dryland fields), shrub, bamboo, degraded forest, deciduous forest, karst, forest, and primary forest. Notably, this also shows that with the proper ground truth data and methods, different types of forest, such as shrub, bamboo, degraded forest, karst forest, and primary forest can be delineated in areas similar to the study area and an overall classification accuracy above 90 per cent can be achieved for these classes.

Another aspect of Tottrup's study was to carry out a temporal land cover change analysis of the study area by using ground-truthing derived from historical interviews to create Forest / Non-forest cover maps. The methodology used was to derive training sets for areas that were known from the interviews and other ancillary data to have not changed land-cover from 1975 to the present. A supervised land-cover classification for 1975, 1992, and 1998 was then derived from a single image for each time period (Tottrup 2001). The land-cover was then grouped into Forest / Non-forest categories following Pathfinder's criteria for forest / non-forest.

The Ca River Basin Study Area

The land-cover in Vietnam's CRB varies from irrigated and rainfed rice paddy in the flat valleys to grass, brush and regenerating forest on the mountain sides, and some older forests on the mountain sides and mountain tops. All of this land-cover has been modified by the human settlements in the area, and some suggest (Fox et al. 2000) that all of the land in Vietnams northern highlands have been used by humans for centuries, if not millennia. Human influence on the landscape includes both small-scale and large-scale agriculture, the cutting of trees for personal and commercial use, and the planting of orchards and tree plantations. In the CRB highland areas, the main land-cover modifications are believed to be caused by the farming systems and logging. A discription of the social and environmental dimensions of the Ca river basin can be found in Tran et al. (2001).

Farming Systems

Rural villages in the CRB depend upon diversified production systems. Elements of the production system include rice paddies, shifting, or swidden, cultivation on hill and mountain sides, the collection of non-timber forest products from forests and fallow areas, small and large animal husbandry, and some hunting and fishing (Tran et al. 2001, Dao et al. 2001, Rambo et al. 1998).

The elements of the production system leave their signature on the landscape. As an example, one can look at the irrigated and rainfed rice paddy areas that are found in valleys where there is adequate water for supporting at least one rice crop. The rice paddies come in various sizes ranging from small rice paddy areas of a few square meters, to large paddy areas of many hectares.

While there is no general model of shifting, or swidden, cultivation in the CRB due to the different practices followed by different ethnic groups, and by different villages, there are some general observations that can be made. In a shifting cultivation system, fields are cleared once a year and may be cultivated for one, two, three, or four years depending upon factors that include traditional practices, a community's land tenure rules, the fertility of the soil, and the amount of weeds. The cleared fields can be of a variety of sizes. Some households in a community will clear individual, fields, in which case the area cleared may be between ¼ hectare and 2 hectares. In other cases, the community may gather and decide that certain areas should be cleared and cultivated during a certain year. In this case the clearing may be larger than 10 hectares (Tran et al. 2001, Leisz et al. 2001).

After the field is abandoned or left fallow, the initial vegetation that grows back is grass. After one or two years, herbaceous and then woody shrubs and brush start to succeed the grasses. If animals, such as cattle and buffalo are introduced into the area, grass will continue as the dominant vegetation. This may also happen if the soil fertility is low. Otherwise, the brush will take over from the grasses over the next few years. If bamboo is present in the area, or was present in the area before it was cleared, bamboo will also slowly take over. Over many years the brush will mature into trees and slowly a land-cover recognizable as "tree-cover" will dominate (Leisz et al. 2001, Fox et al. 2000).

The full regrowth assumes that the community does not re-clear the area for agricultural purposes. In reality, the fields are often re-cleared when they reach the stage of brush mixed with bamboo, or when they are bamboo covered. The time that fields are left fallow range between 2 and 3 years in some areas to upwards of 20 years. The great variation in fallow age is due to the many factors that influence the fallow period. These factors include the population pressure in the community and the surrounding area, soil properties, weed contamination, land-tenure and traditional farming practices (Fox et al. 2000, Rambo et al. 1998 and Leisz et al., unpublished report).

Besides the influence of shifting cultivation on the landscape, people also influence the landscape through their collection of non-timber forest products. Non-timber forest products are collected in the forested and fallow areas (Tran et al. 2001, Dao et al. 2001, Leisz et al., unpublished report). The collection of these products has an impact on the species of trees, brush, bamboo, and grasses that survive in an area and, thus, influence the make up of the vegetation in an area.

Logging

During the 1970s and 1980s large areas of Vietnam's mountains were cleared of trees by large-scale logging operations carried out by the state forest enterprises. However, policy changes implemented at the beginning of the 1990s resulted in a reorganization of the state forest enterprises from natural resource exploitation towards forest protection and reforestation activities. Actually many of the formerly clear-cut areas are now being replanted with trees under such programs as the 327 program and the new 5 million-hectare program. This shift in management can also be observed in the CRB where one can see large areas in the lower regions, which were clear-cut, but now are under afforestation (Tran et al. 2001, Tottrup 2001).

Today clear-cutting no longer takes place in the CRB, rather different forms of selective logging are used. There are a number of reasons for this. First amongst them is the policy changes as noted above and the fact that after the heavy exploitation in the 1970s and 1980s the remaining areas of forest with marketable timber are very remote, and transporting equipment suitable for clear-cutting campaigns is not practicable. Another reason why selective logging is done is that most of the loggers are young men who often travel from lowland areas to the highlands (Tottrup 2001, Rambo et al. 1998). These men usually obtain financial backing from people in the larger towns and cities of the lowlands and travel into the mountains to make money. They spend months, and sometimes years, in the remote areas, cutting trees and floating them down river to sell. Once they have done this they pay back their sponsors.

Selective logging is found throughout the highlands of the CRB, in state forest enterprises, near settlements and in remote areas. State forest enterprises no longer practice clear-cutting. When an area in a state forest enterprise is logged, it is logged selectively (Tottrup 2001). Only the large trees are cut, small trees and woody brush are left behind. Near settlements, local people practice selective logging. According to sources in different parts of the CRB, most of this logging is done to provide for local needs, such as building houses and community structures (Tran et al. 2001, Leisz et al., unpublished report). Occasionally, some of the logs will be floated down river and sold in one of the larger towns. When logging is done, usually the largest and most mature trees are selected for cutting. In the remote areas, selective logging is also practiced. Individuals go into remote forested areas, select the best trees, cut them and drag them out of the deep forest using buffalo. If the trees are on a steep slope, they will be slid down to the bottom of the slope and then drug to the river. After enough logs are cut and gathered at the river side, the logs are floated, one-by-one, to a larger river, where a bamboo raft is built and the logs secured to the bottom of the raft. Then the loggers float the raft down to a major town where they can be sold to buyers, or where the person sponsoring the logger collects them (Rambo et al. 1998, Leisz personal observation 1998).

When trees are selectively logged, a gap in the canopy is created and other types of vegetation quickly grow to fill this gap. This vegetation includes bamboo, grasses, woody brush, and small trees. The land-cover left behind after an area has been selectively logged is degraded forest dominated by tall and medium sized trees, shrub, bamboo, and grass.

Settlement Areas

Another feature of the CRB landscape is that small settlements are scattered over the area. These settlements can cover an area of from less than a hectare to over 10 hectares. They are scattered and the small ones may shift over time, while the larger ones do not. The building material that people use to make the roofs of their huts and houses is grass, bamboo, palm fronds, and in some cases, asbestos tiles. All of these materials reflect electromagnetic radiation in the wavelengths sensed by the satellite remote sensing instruments similarly to bare ground or dry shrubs and will be identified as such in remote sensing images. Also, scattered amongst the houses are grass and shrubs.

Our analysis of the production systems found in the CRB leaves us with the following understanding. First that there is no, or very insignificant on-going clear-cutting of the remaining forest. Second, the vast majority of the logging involves the selective cutting of trees, a process that leaves behind a degraded forest cover. Third, shifting cultivation, swiddening, represents a management practice where forest clearing and forest regrowth exist in a tightly coupled system with rotation cycles ranging from 2 to 20 years. Thus in this and similar environments, in order to capture forest cover dynamics, one needs to map at least the following forest and land cover classes. Three classes consisting of active agriculture areas, fallow areas and tree cover should be mapped in order to adequately capture how the shifting cultivation system impacts on land use and land cover change in the basin. Moreover, grass, brush, bamboo and degraded tree cover should also be mapped in order to help distinguish areas where selective logging has taken place versus areas where the tree cover, or forest, is relatively untouched and also to help better show the impact of the shifting cultivation systems.

Results

Land-Cover Characterisation

Four different land cover classifications available for the CRB were compared to determine how well they characterise the land-cover and the production system found in the study area. It was decided to retain the Tottrup classifications as the reference because of the close to 200 reference sites used for the classification and the in-depth verification of the work and arriving at an overall accuracy of 90.5 % (Tottrup 2002 & submitted). When comparing the different land cover classifications, it must be kept in mind that there is a difference in data acquisition time between the four maps ranging from 1992 (Pathfinder and TREES), 1998 (Tottrup) to 2000 (FAO) that must be accounted for. Classification discrepancies are specifically expected in areas with shifting cultivation.

Table 1 provides an overview of the four maps and a difference in land-cover characterization can be observed. The common areas with clouds have been excluded in the analysis. Discrepancies between the maps are most clearly seen by aggregating the different classes found in the Tottrup, FAO, and TREES classifications into the simplest classification used in the Pathfinder land-cover map, the forest and non-forest distinction. Table 1 shows that the Pathfinder and FAO classifications estimate the amount of forest at 352,072 and 380,920 hectares, while Tottrup shows 275,343 hectares of forest. The same table shows that TREES considers only 155,039 hectares as being forest. The Pathfinder and FAO classify 48,805 and 20,197 hectares as non-forest, while Tottrup considers 124,740 hectares as non-forest and TREES shows 248,708 hectares of non-forest. If a high annual net deforestation rate of 1 per cent is assumed (Tottrup found net annual deforestations between 1975 and 92 to be 0,55 % and between 1992 and 98 to be 0,18 %), this will correspond to approximately 3,000 hectares annually and between 1992 a 1998 18,000 hectares. Consequently the differences observed can not be explained by the difference 1992 – 98 alone.

In table 2, the confusion matrix between the FAO and the Tottrup classification shows that the FAO classification of closed forest is composed more or less equally of the four classes closed forest (29 %), Open fragmented forest (28 %), other woody land (21 %) and other land cover (22 %). With respect to the FAO land-cover class open and fragmented forest the respective percentages are 15, 21, 29 and 34 %. The magnitudes of these discrepancies are beyond what can be attributed to the 2 year difference between the two mapping exercises. Furthermore, table 2 shows that the NOAA AVHRR based FAO land-cover classification can not identify minor fragmented areas, such as bamboo, shrub, farmland, grass etc, where the percent agreement between Tottrup and FAO is 1 and 12 % (other wooded land and other land cover). This is to be expected because of the 1 km size of NOAA AVHRR pixels compared to the 30 m Landsat pixels.

The single date classification made by Tottrup from the 1992 Landsat data (Tottrup, 2002) was compared with the Pathfinder classification from the same year. Though the single date classification is less accurate compared to the multi-date classification (overall accuracy 79 % and 90 % respectively), the confusion matrix confirms that the Pathfinder classification primarily fails to identify the agricultural areas. The non-forest areas from the Tottrup single date classification are composed as 50% forest and 50% non forest in the Pathfinder classification, see table 3. Please observe the high overall agreement of 89 % because of a general good agreement within the forest classes that are eight times more important in area than the non-forest area. Comparing the Tottrup single date 1992 classification with the TREES 1992/93 classification, the greatest discrepancy can be found confusing non-forest with forest, here the TREES classification identifies only 34 % of the non-forest areas in the Tottrup classification. However, the TREES classification appears to map the undisturbed evergreen and seasonal forest well. See table 4.

Figure 2 shows graphically how areas that are farmland, grass, and bare soil in the Tottrup classification have been classified as Forest in the Pathfinder classification, and closed forest, open fragmented forest, and other wooded land, in the FAO classification. It also shows how areas that are shown to be different forest types in Tottrup have been classified as non-forest in the TREES classification. In the CRB the human activities are concentrated around the river (the river can be seen in the Tottrup classification), and it is here that the discrepancies between the four classifications are most pronounced. The consensus between the maps increases as a function of the distance from the river and as the percentage of closed forest increases.

Temporal Land-Cover Change Analysis

It can be argued that the exact mapping of specific land-cover areas (their seize) is less important if the mapping at least is consistent in time (same land-cover is mapped the same way) and hereby provides valuable information about the overall trends. To test the different land-cover classifications' consistency over time, a comparison of the Pathfinder temporal data from 1975 and 1992 was made with the Tottrup temporal data from the same period. Table 5 shows the comparison of forest areas for the different classifications and the resulting deforestation rates for the study area. The two classifications are using the same Landsat MSS and TM images. Tottrup shows a larger area cleared and a smaller area of regrowth between 1975 and 1992 than Pathfinder does. Tottrup shows a magnitude larger amount of gross- and net-deforestation compared to the Pathfinder dataset.

Discussion

Land-Cover Characterisation

With regards to accurately characterising land-cover, the classification schemes examined, other than Tottrup, fail to deliver pertinent information about vegetation morphology making it difficult to identify where forest exploitations take place in the area. The results shown in table 1 and the confusion matrices in table 2, 3 & 4, show that land-cover types such as grass, farmland, rice paddy, and even bare ground are being classified as forest in the FAO and Pathfinder classifications. In the TREES classification, the results indicate that areas such as karst forest, degraded forest, bamboo, and shrub are being considered non-forest, thus inflating the non-forest category.

The failure of the classifications to provide pertinent data about vegetation morphology also impact on the different classifications usefulness in helping make sense of the CRB production systems impact on the land-cover. Because the simpler classifications are limited to presenting all land-cover as one of a few broad classes, the intricacies of the landscape dynamics are lost. These classifications do not reflect the changing quality of the land-cover, such as the way the quality of the broad "forest" class may range from a relatively untouched "primary" forest to a "degraded" forest, to an area dominated by bamboo and brush, or the way the "non-forest" class may range from rice paddy, to upland agricultural fields, to bare land and grass dominated areas. Discriminating between these classes is ultimately important, as these classes directly reflect the reality of how the land is used in the CRB. These classes, for example, are indicative of where swidden cultivation is taking place, where selective logging is taking place, where settlements are, and where non-timber forest products might be gathered. This information is important to any policies that are made regarding the regulation of how land is used in the area. Table 6 illustrates how the Tottrup approach of using multi-date imagery captures the relationship between the production systems land-use and the land-cover found in the CRB. If the density of selective logged trees is low, it is difficult to identify this from Landsat satellite images and further research is needed in this area, possible using radar remote sensing.

Temporal Land-Cover Change Analysis

With respect to temporal land-cover change analysis, the analysis of tropical deforestation and forest degradation derived from these classifications fails to document whether clearings are permanent and cannot indicate whether the forest is being degraded (e.g. whether its morphology is changing). In Table 5 the satellite data are the same for the Tottrup and Pathfinder classifications, therefore, any inconsistencies in the results are related to the methodologies applied and the definition of forest that is used. Tottrup uses a definition of forest that includes primary forest, karst, deciduous forest, degraded forest, bamboo, and shrub. Officially, Pathfinder uses the same definition (Brunner et al. 1998). However, as already noted, the Pathfinder approach seems to also classify areas of non-forest, farmland, grass, bare soil, paddy, etc., as forest. De facto, it appears that Pathfinder classifies pixels as forest if they have any vegetation on them when the image was acquired. In other words, Pathfinder appears to represent a classification of "vegetated" vs. "non-vegetated" pixels. This means that the Pathfinder classification in general has more forest cover than Tottrup's classifications. Consequently, as shown in Table 5, Pathfinder underestimates deforestation rates for the study area.

The underestimation of deforestation results for the following reason. By the definition used, a deforested pixel is a pixel that has been classified as forested at time one and non-forested at time two. However, the very broad forest definition that, as noted above, is used by Pathfinder, is likely to miss the majority of changes happening within the production systems of the CRB. Due to how the production systems work, only a very few areas will actually be without vegetation for a very long time. Thus, the Pathfinder approach can pick up a grass area at time 1, that has been stripped of vegetation at time 2, and term it deforestation. A primary forest area in 1975, however, that has become a grass area in 1992, or even farmland, can still be classified as forest in 1992 and, thus, will not be identified as deforested. Because FAO and TREES use similarly broad classifications, given the production system of the area, similar errors are expected to creep into their assessments of changes in forest area. This situation is exacerbated for Landsat by the image acquisition times. The 1992 image is from October, when upland fields may still be covered by healthy rice crops that can be considered as "forest" by Pathfinder, while the 1975 image is from January, after harvest, when the rice crops would have been harvested and fields cleared of vegetation.

Under the Tottrup approach a deforested pixel is equally a pixel that has been classified as Forest (excluding grasses) at time one and that has been classified as non-forest (i.e. non-vegetated and farmland and grasses) at time two. This approach is more reliable in the sense that it takes into account some of the dynamics related to the fast recovery of vegetation after deforestation.

Finally, it should be mentioned that Pathfinder appears very unreliable with regard to regrowth. An examination of where the regrowth appears to take place in the Pathfinder images shows that a large part of the regrowth pixels are obviously related to paddy cultivation in the lowlands. However, very limited regrowth is found in the shifting cultivation dominated highlands, which is where one would expect regrowth to dominate. An analysis of the reason for this shows that paddy is harvested (summer rice) or just sown (spring rice) in January, when the 1975 image was acquired. Thus, these areas would appear as bare soil in the image. In October, when the 1992 image was acquired, the summer paddy is flourishing. Therefore these same areas will appear as heavily vegetated in the image and, given the proclivities of Pathfinder that have been mentioned above, these same areas are considered forest in 1992.

Conclusion

It has been shown in the Ca river basin that the general broad classifications, such as Landsat Pathfinder, FAO and TREES fail to characterize the production system. The Pathfinder and FAO classification are not able to identify the degradation of primary forests and the TREES classification can not be used to identify and locate areas with agricultural activity. Land-cover types that fall under the general classes of “other land” and “other woody land” are usually fragmented and within the broad classifications they are assigned to the “forest” classes (Pathfinder and FAO) and non-forest (TREES, here including degraded forest). Consequently, the forest area is exaggerated as in the Landsat Pathfinder and FAO classifications and underestimated in the TREES classification. Information about where people are active and how production systems in an area influence the land-cover can not be extracted from these broad maps.

It is expected that the broad classifications do not classify the individual classes with a high precision, but it is expected that the broad classifications are consistent over time, e.g. they must have the same bias from one period to another in order to provide reliable information on land-cover and land-use dynamics. However, a comparison of the general Pathfinder classifications from 1975 and 1992 with classifications elaborated specifically for the CRB by Tottrup for the same years shows that this is not the case. Because bamboo, shrub, swidden agriculture, grass, and paddy all contribute to the forest class in Pathfinder, agricultural expansion will not be captured by this classification and consequently the gross and net deforestation are underestimated by a factor of two.

Thus, the overall conclusions of this study are that:

- Remote sensing cam be used to map tropical forests and hereby derive pertinent information on the production systems of an area; however, appropriate methods must be applied as shown by Tottrup (2002). Here land-cover mapping accuracies greater than 90% were achieved by using multi-date classifications of Landsat imagery and giving priority to field verification.

- For national or local management of tropical forests, and land-cover in general, the use of the broad global or regional classifications can not be recommended, since the inherent bias in these classifications will provide wrong information on the land-cover and its change over time. In the present paper it was shown that three broad classifications all failed to identify the agricultural areas and their associated land-cover classes and separate them consistently from the forest class. Furthermore, in some cases the broad classifications do not address the issue of degraded forest, and in other cases the estimates are wrong.

- It can not be recommended to use simplified classification approaches in areas where there is no in-depth available information on the production- and ecosystem. In the Ca River Basin the distinction between agriculture and clear-cut areas can not be made using a simple criterion on the size of the clearings as has been suggested.

The future perspectives are that:

- Applying the techniques used by Tottrup to successively map tropical forest areas on an annual basis or with intervals of only a few years can provide further improved information on the dynamics of the forest and the production system associated with it. The use of the new data from the Modis and Meris instruments provides interesting perspectives with the improved radiometric, temporal (compared to Landsat) and spatial (compared to NOAA AVHRR) resolution. The improved radiometric resolution improves the discrimination capability of delicate vegetation and forest classes. The improved temporal coverage means better information on vegetation phenology, agricultural calendar and human activities in general.

- Using remotely sensed data to map tropical forests needs to be improved vis-à-vis the identification of areas where selective logging is taking place, or has taken place. Studies with radar instruments have shown encouraging results, however, further research is needed.

- Further studies should identify how the approach presented here, of understanding the ecosystem and production system combined with a detailed classification such as Tottrup, can be generalized to cover regional areas and forests. Important regional bias in the classification scheme is likely to be identified from auxiliary data such as digital elevation models, population statistics and time series of remote sensing data explaining the vegetation dynamics.

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Table 1. A Comparison of Areas in hectares of Land-Cover Type by Land-Cover Classification Scheme. Minor differencies in the total orignate from diferencies in pixel size between Landsat and NOAA AVHRR data.

Land-Cover Type	Pathfinder 1992 (hectares)	FAO 2000 (hectares)	TREES 1992/93 (hectares)	Tottrup 1998 (hectares)
Forest	**352072**	**380920**	**155039**	**275343**
Closed Forest		**196844**		
Evergreen Forest			**154863**	
Primary Forest				81668
Karst Forest				4991
Seasonal Forest			**176**	
Deciduous Forest				48
Open fragmented forest		**172091**		
Degraded Forest				95537
Other Wooded Land		**11984**		
Bamboo				52837
Shrub				40262
Non-Forest	**48805**	**20197**	**248708**	**124740**
Other Land Cover		**20197**		
Non-Forest			**248708**	
Farmland				53972
Grass				57728
Bare Soil				10240
Paddy Rice Area				742
Built up area				1510
Sand/rocks				547
Water	**2026**	**2631**		**3838**
Clouds (near river bank – not really clouds)	**1142**			
CLOUDS COMMON TO ALL	53497	53782	53782	53622
Total	457542	457529	457529	457542

Table 2. Confusion matrix showing agreement between Tottrup and FAO classification by number of pixels.

	FAO						
Tottrup	**Closed Forest**	**Open & Fragmented Forest**	**Other Wooded Land**	**Other Land**	**Water**	Total (Pixels in Tottrup Classification)	Percent (Agreemenet between Tottrup & FAO Classification)
Closed Forest	**632135**	**285324**	**26619**	**17015**	**2**	961095	66 %
Primary Forest	608799	254987	26078	15222	2		
Karst	23335	29800	541	1793	0		
Deciduous Forest	1	537	0	0	0		
Open Fragmented Forest (Degraded Forest)	**615538**	**410597**	**21627**	**12889**	**121**	1060772	39 %
Other wooded land	**458552**	**547640**	**6296**	**20806**	**1204**	1034498	1 %
Bamboo	267685	304844	3369	10733	449		
Shrub	190867	242796	2927	10073	755		
Other land cover	**472974**	**653401**	**75602**	**160695**	**23698**	1386370	12 %
Farmland	219739	285094	29444	54771	10762		
Grass	234646	322579	26097	53994	4264		
Bare Soil	12866	33622	16757	43409	7222		
Paddy	1420	4932	446	1105	339		
Built up area	3438	4680	2241	5415	1006		
Sand/rock	865	2494	617	2001	105		
Water	**7571**	**14953**	**2953**	**12974**	**4201**	42652	10 %
Total (Pixels in FAO Class)	2186770	1911915	133097	224379	29226	Total Pixels = 4485387	
Percent (Agreement between FAO & Tottrup Classification)	29 %	21 %	5 %	72 %	14 %	Total Pixels in agreement between both classifications = 1213924	Overall Agreement = 27%

Table 3: Confusion matrix showing the agreement between the Pathfinder 1992 and the Tottrup single-date 1992 classifications. Numbers are in pixels.

	Pathfinder 1992				
Tottrup 1992	**Forest**	**Non-forest**	**Water**	Sum Tottrup	Percent agreement between Tottrup and Pathfinder
Forest	3706666	45063	352	3752081	98,79 %
Non-forest	486615	483268	736	970619	49,79 %
Water	2306	4951	16265	23522	69,15 %
Sum Pathfinder	4195587	533282	17353		
Percent agreement between Pathfinder and Tottrup	88,35 %	90,62 %	93,73 %		Overall agreement = 88,62 %

Table 4: Confusion matrix showing the agreement between the TREES 1992/93 and the Tottrup single-date 1992 classifications. Numbers are in pixels.

	TREES 1992/93			
Tottrup 1992	**Forest***	**Non-forest**	Sum Tottrup	Percent agreement between Tottrup and TREES
Forest	1926663	1825444	3752107	51,35 %
Non-forest**	60720	951025	1011745	94,00 %
Sum TREES	1987383	2776469		
Percent agreement between TREES and Tottrup	96,94 %	34,25 %		Overall agreement = 60,41 %

** The sum of the two TREES classes - evergreen forest and seasonal forest.*

*** Including water*

Table 5: Comparison between deforestation rates derived by Pathfinder and Tottrup respectively.

	Pathfinder (area in pixels)	**Tottrup (area in pixels)**
Forest 75	4360926	4137026
Forest 92	4195587	3752107
Cleared	304286	492348
Regrowth	130962	107650
Difference	173324	384698
Gross-deforestation (overall)	**6.98 %**	**11.90 %**
Gross-deforestation (annual)	**0.41 %**	**0.70 %**
Net-deforestation (overall)	**3.97 %**	**9.30 %**
Net-deforestation (annual)	**0.23 %**	**0.55 %**

Table 6. Production activities found in the Ca River Basin Production System, the resulting Land-Use, Land-Cover and how the corresponding Tottrup class.

General Activity	Specific Action / Process and use of land	Resulting Land-Cover	Tottrup Class
Logging	Clear cut logging	Large areas with no vegetation for one to two years	Bare soil, grass or shrub (depending on the amount of time since clear cut)
	Selective logging	Change in Forest Morphology – Largest trees are gone, gaps in forest canopy, canopy is not even, degraded forest	Degraded forest
Swidden / Fallow Agriculture	Clearing for active swidden – upland agriculture	Areas cleared of vegetation before planting and after harvest. Areas range in size from ¼ ha to 10 ha	Agriculture
	Fallow first year regrowth – use for NTFPs and grazing	Predominantly grass covered. Areas are the same size as those of the previously cleared active agricultural areas.	Grass dominated
	Fallow medium term regrowth (2 – 7 years) – use for NTFPs, grazing, firewood	Covered by grass, brush and some bamboo. Areas will be roughly the same size as the previously cleared agriculture areas, but will vary as the rate of regrowth varies.	Grass, brush or bamboo depending upon the dominant land cover
	Fallow long term regrowth (8 – 20 years) – use for NTFPs and firewood	Bamboo dominated, tree and bamboo mixed, or tree dominated areas. Roughly the same size as the previously cleared agriculture areas.	Bamboo or degraded forest depending upon the dominant land cover
Rice Paddy Agriculture	Irrigated or flooded paddy fields – wet rice agriculture	Cleared areas during the dry season, flooded or mature rice vegetation during the rainy season.	Agriculture (rice paddy)
Settlements	Housing area	Permanently cleared areas. Settlements are located near permanent agriculture fields.	Agriculture or bare land

Figure captions

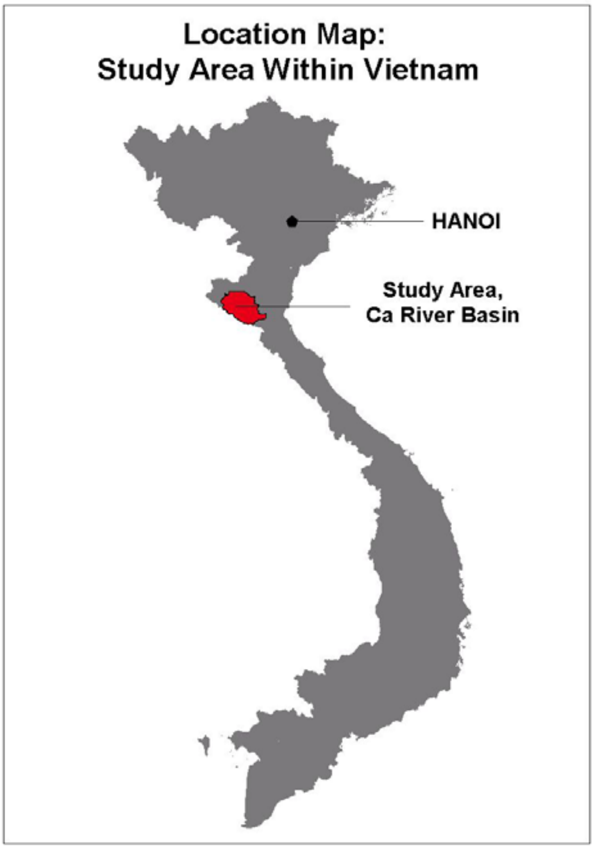

Figure 1. Location of the study area, the Ca river basin in the northern Vietnam.

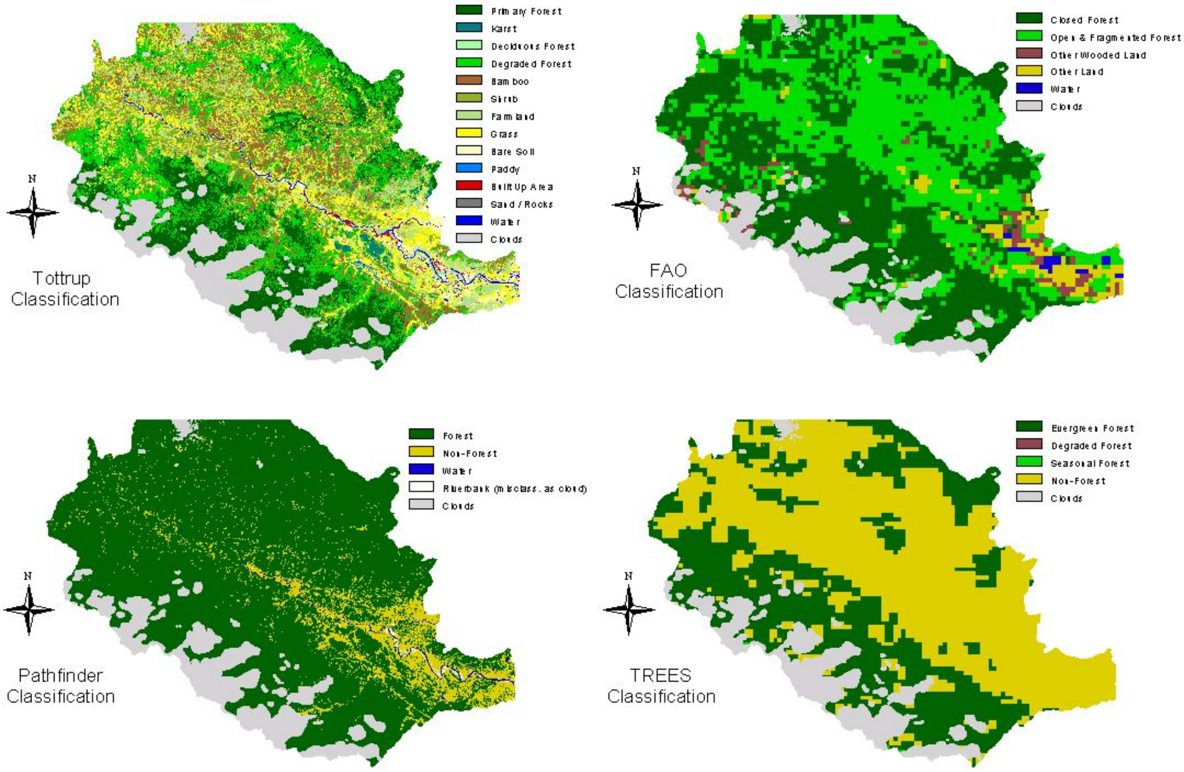

Figure 2. The four classifications, Tottrup, FAO, Pathfinder and TREES with legends.