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Change in vegetation cover in East Timor, 1989–1999

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Abstract

Forest resources play a key role and provide many basic needs to communities in developing economies. To assess the patterns of vegetation cover change, as a corollary of resource utilization, satellite imagery, ground truth data, and image processing techniques can be useful. This article is concerned with identifying change in major vegetation types in East Timor between 1989 and 1999, using Landsat Thematic Mapper data. The results highlight a significant level of deforestation and decline in foliage cover. All major vegetation cover types declined from 1989 to 1999, and there was a sizeable increase in degraded woodlands. This decline has had considerable impact on the livelihoods of rural and urban communities. Causes for these changes include: economic exploitation of abundant resources; and implications of transmigration policies implemented during Indonesian rule, resulting in increased competition for land and woodland resources. As the new nation of Timor-Leste establishes itself, it must consider its current stock and distribution of natural capital to ensure that development efforts are geared towards sustainable outcomes. Without the knowledge of historical patterns of resource consumption, development efforts may, unwittingly, lead to continuing decline in forest resources.

Keywords: Timor-Leste; Vegetation cover; Remote sensing; Deforestation; Natural resources management; Dense forest; Forest; Woodland

Introduction

On 20 May 2002, after more than 400 years of colonial influence, East Timor (now Timor-Leste) gained its independence, and was hailed as the newest nation in the world. Between 1975 and 1999, East Timor was a province of Indonesia under military occupation. As a consequence of the significant internal struggle in East Timor during this period, only limited data and information could be gathered regarding the status of vegetation cover and change. As the Republic of Timor-Leste establishes itself as an independent State, it is important that the condition of its natural resource base be considered in nation building and development of its economy.

Deforestation is considered to be one of the most significant environmental problems (Sandlund et al., 2001). Quantitative assessment, using remote sensing techniques, revealed that 16% of forested land had been completely cleared between 1972 and 1999 (Erikstad et al., 2001). Suggested causes for this are swidden agriculture, clear- cutting, wildfire and excessive logging during Indonesian rule (Sandlund et al., 2001). Aditjondro (1994) supports the argument that excessive logging by Indonesian companies, through their monopolization of timber resources, played a significant role in deforestation in East Timor. There is also support for the theory that Indonesian policies of demo-graphic engineering (transmigration and relocation of villages), in conjunction with military presence in the western districts and main centres, and arrangements for commercial resource extraction, had significant impacts on the status of natural resources and vegetation cover (Tirtosudarmo, 2000; Rio, 1999; Aditjondro, 1994; Budiardjo and Liong, 1984).

Aside from the share in deforestation attributable to Indonesian population policies and extraction, there is also evidence that land use, pressure from population growth and swidden agricultural practices had caused an imbalance in natural resource utilization prior to the 1975 –99 period, especially in the Baucau–Viqueque region (Metzner, 1977). In fact, there is significant evidence for the theory that poor developing countries in the region, such as East Timor, are subject to resource degradation due to competition for resources by communities to maintain subsistence livelihoods (Ellorin, 2002; Ghee and Valencia, 1990).

In terms of these issues, an essential question for any further research regards the pattern of change in the East Timor landscape and the attribution of possible causes and consequences. With this question in mind, the study described in this article was designed to improve factual knowledge about vegetation cover change in East Timor between 1989 and 1999. The study uses supervized classification of satellite imagery (Landsat Thematic data) and post-image processing to determine patterns of coverage of dominant vegetation cover types and the changes in the study area over the period. The study focuses on the western part of East Timor (Figure 1).

Methods

Field data collection and categorization

Field checking was undertaken on three occasions: 16 /17 December 2000, 2 August 2001 and 13 –16 September 2001. During the field visits, approximately 50 sites, representative of land cover and vegetation type were sampled. Data on structure of vegetation cover, altitude, canopy height and foliage projected cover (FPC) were collected with a Global Positioning System unit (± 8.0 m accuracy). Field sites were selected to represent all types of vegetation in all regions covered by the satellite images. Due to lack of roads and inaccessible terrain, the investigation was limited to sites within a few hundred metres of a road and below an altitude of 1860 m. Land cover and vegetation types were grouped into broad categories (Table 1). In addition, black and white aerial photographs from 1989 covering the study area (1:30,000) were used to either verify or determine the ground cover and to help interpret the 1989 satellite image. Surface features were analysed with a 10× stereoscope.

Land cover classes were derived from foliage projected cover (FPC) collected in the field. Foliage projected cover is the cover of any vegetation strata and the pro- portion of the ground below it that is shaded if the sun is shining vertically overhead. Only four classes were used for this variable: <10%, 10 –30%, 30 –70%, and >70%. The classification method used in this study follows that used by AUSLIG (1990). Using these categories, ecosystems that contain less than 30% foliage projected cover are defined as woodland (Hobbs and Yates, 1997). Those that have above 30% FPC are forest categories (Table 1). Categories with less than 10% cover, such as heath/shrub communities were classified according to height of vegetation since they are dominated by low perennial foliage.

A two-dimensional framework of foliage projected cover (FPC) adopted in this study is a very useful model of monitoring vegetation structure. Its main advantage is that it takes into account both cover (abundance) and structure (vertical distribution of biomass) (Graetz, 1989). An additional advantage of the FPC framework is that it uses the same vertical perspective as remote sensing instruments do. Spectral signatures representing different land cover types (dense forest, forest, plantation, forest/coffee, wood- lands, degraded woodlands and others) were plotted against the waveband and related to the FPC.

There were no rainfall data available for 1989 or 1999 (http://climexp.knmi.nl/). However, from the appearance of lakes in the images, it could be deduced that the period prior to September 1989 was comparatively drier than that before September 1999. Fox (2000) mentions that after the drought related to the 1997–98 El Niño, East Timor had experienced wet conditions consistent with the La Niña pattern. This corroborates our observations of the 1999 satellite data.

Whilst the following results review changes in all land cover categories (Table 1), this study is concerned primarily with the measurement of change for the major eco- system types; dense forest,

forest and woodlands (including degraded woodlands). Degraded woodlands in the context of this study are those that are subject to constant burning by farmers, or excessive grazing and fuelwood harvesting, and as a result have less FPC, species and cohort diversity than woodlands not subject to these stresses. In an economic and utilitarian sense, however, these woodlands are of value to local communities.

Remotely sensed data

This study used two co-registered and georeferenced (orthocorrected) Landsat TM (Thematic Mapper 5 and 7) images provided by the Australian Centre for Remote Sensing (ACRES). Images were registered to the MGA94 Map System. Thermal band (Band 6) was not used. The data were from 20 September 1989 and 8 September 1999. The 1999 image clearly shows a number of smoke plumes in the capital, Dili, as a result of the violence and destruction following the 30 August referendum for independence.

Dark pixel correction was applied to overcome differences in atmospheric conditions (Milton, 1994). Since only the results of classification of 1989 and 1999 images were compared, it was deemed unnecessary to carry out any further radiometric corrections (Jensen, 1996).

A number of areas were masked out on the images: seas surrounding the island, West Timor territory and clouds and shadows. Since only the 1999 image had cloud contamination, the cloud mask was applied to both images only when comparing data between 1989 and 1999. Because there was a difference in height of the tide between 1989 and 1999, the high tide level was used to create a water mask. This meant that most of the mangroves (northern shores of the island) were excluded from the analysis.

Approximately 50% of the East Timor territory was not covered by the images (Figure 1). Approximately half of the study area falls within so-called ‘northern uplands’ (ARPAPET, cited by Fox, 2000), with altitudes above 500 m above sea level. The average rainfall within the study area is quoted as <1,000 mm for the north coast, <1,500 mm for the northern uplands and 1,000 –1,500 mm for the remainder of the area. Metzner (1977), Rio (1999) and Fox (2000) provide a good overview of the geography and environ- mental conditions in East Timor.

Image processing techniques are described in the appendix.

Cross classification analysis

The cross-classification technique was used to compare the classification results (Eastman, 1999). Cross-classification can be described as a multiple image overlay showing all combinations of the logical operation. The result is a new image that shows the locations of all combinations of the categories in the original images. So, for example, if forest was present at a particular location in 1989 and in 1999, that pixel is allocated a different value than another location, where forest was present in 1989 but not in 1999 (Figure 2). Therefore, this method allowed an analysis of changes in pixel membership between 1989 and 1999.

Other post-image processing analysis techniques to sup- port findings in this study were applied. These included:

- The measurement of dense forest and forest areas to examine trends in patch sizes between 1989 and 1999. Two measures were used, including; number of patches and mean patch size

(University of Connecticut – http://resac.uconn/research/forestfrag/).

- The examination of the distribution of forest and wood- land resources between the two time frames. With the addition of population data, this allowed an assessment of consumption of timber resources over time, providing an indicator of the loss of timber resources, or the scarcity of general forest resources due to low forest cover (Gardner-Outlaw and Engelman, 1999).

The following reviews the results of analysis looking at the changes in land-cover classes and changes by district in the dense forest, forest and woodland categories. This will be followed by a review of the deforestation and vegetation change determined in the study area and time period.

Changes in land cover 1989 to 1999

The single largest type of vegetation cover in 1989 was woodland (nearly a third of the study area). Of other non- agricultural cover types, forests and degraded woodlands were the second and third largest category (Table 2). This was in contrast to the situation in 1999, when degraded woodland covered the largest portion of the area (apart from agricultural land), followed by woodland and forests (Table 2).

The differences in vegetation cover between 1989 and 1999 demonstrate a decline in dense forest, forest and wood- land areas. The largest decline was noted in the woodland category. Increases in areas of modified plantations, including coffee plantations, were also detected. However, the largest single increase in land-cover type from 1989 to 1999 occurred in the degraded woodlands category.

There were decreases in dense forest cover in all districts examined, except for Manatuto and

Manufahi, where cover increased (Table 3). Significant percentage declines occurred in Oe-cusse, Covalima, Liquica and Bobonaro. Changes in forest cover were more variable, however. Declines in forest cover occurred in Covalima, Ainaro, and Manufahi. Some districts showed an increase in forest cover, includ- ing Liquica, Ermera and Oe-cusse (Tables 2 and 3). There was a decline in woodland cover between 1989 and 1999 in all districts. Significant losses of woodland area occur- red in Bobonaro, Oe-cusse, Manatuto, Ermera, Aileu and Liquica (Tables 2 and 3).

The study concentrated on processing remotely sensed data to examine the extent of change in vegetation cover in the western portion of East Timor during the period 1989 – 99. The results clearly indicate a decline in most districts. However, the results do show that some increases occurred in structural density. It is recognised from research that trop- ical woodlands and forests, if left undisturbed for a period of time, will increase in density (Fensham and Fairfax, 2002). Therefore, whilst the results show significant decline in vegetation across the study area, some areas were less affected by causes of change, resulting in increases in structural density of vegetation. The extent of deforestation and structural decline will be examined in the following section.

Deforestation and loss of vegetation cover

The use of the term deforestation needs some definition at this point, given the variations that can be applied to the concept. Within this article, deforestation is considered to be the complete loss of vegetative cover to a point below UN Food and Agriculture Organisation (2000). In the analysis of remotely sensed data, the term deforestation may suggest conversion of land areas to another land use, such as agriculture. However, this may not always be the case and specific agricultural land uses are difficult to determine without undertaking extensive groundtruthing. The loss of vegetative cover reported in this article, measured in terms of reduction in FPC, is the depletion of timber/forest resources to a point not less than 10% FPC. As such, this is not considered as deforestation under the definition used by FAO.

Total deforestation, established in the study area for the 10-year period, was approximately 18.19%. This was deter- mined using cross-classification techniques and defined as the conversion of land from any of the vegetation categories with a FPC of greater than 10% (i.e., dense forest, forest, forest /coffee, plantation, woodland and degraded woodland) to a land-cover category that contained less than 10% FPC (i.e., either heath, agriculture or other). Using the same method this study calculated the net loss of vegetation from the categories of dense forest, forest and wood- land to cover classes with less than 10% FPC. Results reveal woodland areas were reduced by 14.6%, followed by dense forests, 8.7% and forests at 3.9% (Table 4).

Using these figures, the loss of, or reduction in, FPC, for the three ecosystem types was also calculated using the total change less deforestation (Table 4). Loss of FPC is a shift from one class to another class with less FPC. Results show a reduction of FPC from dense forest of 23.7%, while forest declines were marginal at 3.1%, and woodland FPC was reduced by 40.6% for the 10 year period.

These results reflect changes in the three categories of dense forest, forest and woodlands for the study area of the western portion of East Timor. Annual rates of change can-not be determined given that there are no data available.

Recent work undertaken by Erikstad et al. (2001) using remote sensing techniques revealed changes in land surface cover between 1972 and 1999 that provide a source of reference for the present study.

The broad scale evaluation of the 2001 study seeks to determine the extent of deforestation in East Timor based on two satellite images using unsupervized image classification for three main land-cover categories: dense forest, sparse forest and no forest.

Results from Erikstad et al. (2001) show a decline of 16% in dense forest and sparse forest area over the 27-year period. However, in interpreting these results, some observations should be made:

- The authors state that some regional differences between the western and eastern end of East Timor are obvious. That is, the western part of East Timor has suffered more loss of dense forest cover than the eastern part.
- The classification descriptions used by these authors are assumed to equate sparse forest to woodland, and dense forest to the dense forest and forest categories of the present article.

Clearly however, the results from our study agree with those of Erikstad et al. (2001), and correlate in terms of the scale of deforestation in East Timor.

Transformation of the landscapes of East Timor

Natural resources and development

The importance of agriculture to East Timorese society is described by da Costa (2001) as ‘vital’ due to the fact that it employs over 80% of the population, contributes 40% of GDP and 90% of foreign exchange. The historical development of agriculture has been shaped by the environment, colonial development policies and the introduction of crops causing successive transformations over time

(Fox, 2001). The predominant forms of agricultural practice have also been described by Fox (2001) as shifting agriculture on ridges and mountain slopes with more intensive agriculture on river banks and alluvial plains. The traditional practice of slash and burn agriculture has shaped the present day landscapes of East Timor (Fox, 2001). From a policy perspective, colonial interests have generally focused agricultural development initiatives in either the eastern half (under Portuguese rule) or the western half (under Indonesian rule). It is the impact of landscape change in the western half that is examined here, based on the data now available from remote sensors.

In view of the predominance of agriculture in the East Timor economy, the role of the environment and the indigenous natural resources can be seen from a number of perspectives:

- From a macroeconomic perspective, the greater the stock of natural resources per capita, the greater the country's relative advantage in primary production as a growth sector (da Costa, 2001).
- From a socio-economic perspective, heavy reliance on forests and woodlands in sustaining livelihoods requires the sustainable management of the environment and associated ecological services.
- From an environmental perspective, the integrity of forested areas is an important principle which serves to maintain biodiversity and ecological value.

East Timor's heavy reliance on natural capital is indicated by the fact that there is little off-farm wage supplement available within the agricultural sector (Booth, 2001). Thus, as off-farm or non-agricultural sources of income are un- available, supplements to individual/community livelihoods must come from surrounding forest and woodland areas.

From these perspectives and in view of the results from the study, it is argued here that previous development (and exploitation) policies have led to a significant decline in the indigenous natural resources base, which is fundamental to the agrarian economy and the pattern of life in East Timor. This situation, in turn leads to further environmental decline and other secondary impacts.

Distribution and use of natural resources

In the traditional rural communities of East Timor, people rely on natural resources to a large extent. This can be broken down into two roughly dominant forms of resource use, depending on the forest type and cover abundance. Firstly, the forest (those with FPC >30%) provides not only timber but also a variety of medicinal and food items, building and household materials, such as game, medicinal herbs, honey, mushrooms, wax, etc., as well as intangibles, such as spiritual values (Metzner, 1977; Hill and Saldanha, 2001; Sandlund et al., 2001). Secondly, woodlands (areas with 30% FPC) supply some of the same items, and are a primary source of fuelwood and serve as grazing areas for livestock (Matthews et al., 2000).

By utilizing available population figures[1] combined with the data generated in this study, it is possible to examine the stock of forest /woodland cover. In 1996, the UN Inter- governmental Panel on Forests (IPF) proposed the concept of ‘low forest cover’ to draw attention to the economic, environmental, and social consequences of pressure on forest resources in countries ‘at risk.’ The at-risk threshold was set at 0.1 ha /capita (Gardner-Outlaw and Engelman, 1999).

[1] The population data were obtained from two sources: for 1989, the surrogate measure of 1990 was applied from Fox (2001); and for 1999, Indonesian census figures from *Biro Pusat Statistic, Timor Timur* (Central Bureau of Statistics, East Timor) 1996 and 1997.

The impact of population increase on vegetation cover/ capita translates to a decline in the availability of all vegetative resources per capita (Figures 3 and 4). This means declines in all districts that had higher levels of dense forest and forest areas per capita in 1989. There was a marked decline in woodland cover/capita in all districts and significant increases in degraded woodlands. Significant declines in dense forest, forest and woodland cover is apparent in all districts, with the exception, perhaps, of Dili (as its cover was already significantly reduced) and to some extent Manufahi.

In 1999, the distribution of resources for many districts was close to or below the 0.01 ha /cap threshold (Figure 4). The lower the indicator, the more difficult it will be for communities to supplement their livelihoods. This is critical, particularly for the Dili urban community, given the increasing reliance on fuelwood for cooking since subsidies on kerosene were removed by the Indonesian Government (Sandlund et al., 2001). Vegetation cover is very low in the Dili area, and almost as low in the districts of Ermera, Liquica and Oe-cusse. Moreover, as scarcity increases, so do potential price impacts, and it becomes more difficult for families to pay for essential fuelwood supplies.

Rural areas with little forest or dense forest cover, are likely to feel the impact on the ability of communities to fulfil their needs for timber and non-timber forest products. This is already occurring in some instances, where communities are experiencing greater difficulty in locating and harvesting medicinal plants (Sandlund et al., 2001). It is clear that a shrinking forest and woodland resource base will limit the opportunities for communities and families to meet their basic needs.

Apart from the social and livelihood impacts of declining forest /woodland resources, loss of vegetative cover also has immediate physical impacts on soil stability, especially in topographically steep landscapes, such as those of East Timor. Loss of vegetation compromises watershed stability;

causes loss of arable land; increases sedimentation of waterways and irrigation systems, as well as coral reefs; and contributes to contamination of drinking water sup- plies. The continuing low level of vegetation cover is likely to exacerbate these problems.

Forest cover and the environment

Green areas with a FPC greater than 30% (dense forest and forest) were examined to assess the change in forest patch size and frequency. The analysis of forest fragmentation concentrated on the FPC categories >30%, because from a conservation perspective, tropical forests contain a greater diversity of species than most major habitat types (UNEP, 1995; Matthews et al., 2000). However, Sandlund et al. (2001) argue that the small area would result in lower diversity with higher endemism.

Four districts were examined: Dili, as this district had the least area of dense forest and forest; Covalima and Bobonaro, which had the greatest loss of forest and dense forest within the ten-year period; and Manufahi, which had the least loss of vegetative cover. These four districts all showed increases in the total number of patches and declining mean patch size between 1989 and 1999 (Table 5). Covalima and Dili in particular had a significant reduction in average patch size.

It is well known that fragmentation of forest areas induces certain problems, including:

- Edge effects. Patch size and patch shape influences the ratio of forest edge to interior.
- Isolation. Habitat isolation may reduce immigration of fauna, influencing species richness in tropical forest fragments (Turner, 1996).
- Patch size. Smaller patches of remnant forest areas are known to host less biodiversity, as many avian, primate and mammal species have insufficient range within the smaller areas

(UNEP, 1995).

- Vulnerability. Smaller forest patches are more vulnerable or susceptible to damage by fire, insects or other factors.

Within the study area, where forest patches are declining in size, biodiversity conservation and protection of natural areas and representative ecosystem types should be a key issue for forest management.

4.4. Driving forces of landscape transformation 1989–99

In view of the loss of natural forest resources, and the consequences of deforestation and degradation of woodlands, social development and environmental rehabilitation are of special significance to the ability of this new nation to develop its economy. However, it is also important to review some of the causes of this change in the context of East Timor, with specific reference to the time frame of the present study.

4.4.1. Exploitation of abundant resources

It has been put forward that East Timor's natural resources were monopolized by Indonesian business interests (Aditjondro, 1994; Budiardjo and Liong, 1984). This group of companies were linked to the Indonesian military establishment in East Timor, and essentially financed its operations (Aditjondro, 1994).

The implications of Aditjondro (1994) and Budiardjo and Liong (1984) are that the forestry resources were controlled by Indonesian companies, who sought to maximize extraction, rather than use sustainable logging practices. Rio (1999) states that Indonesian logging activities were of a significant order, whilst Sandlund et al. (2001) provide anecdotal evidence on over-exploitation of timber and mismanagement of forests under Indonesian rule.

Logging of forest areas without formal permission was also occurring during the period of the transitional UN administration (1999–2002), suggesting an arrangement involving corporate sponsorship (author, personal experience). It is argued here that the level of deforestation and decline in FPC shown in this study could not have come about from the subsistence strategies of poor rural communities, relying on farming with minimal capital inputs. Labour and machinery requirements to clear large trees, and transport facilities for logs are outside the means of the local subsistence farmers, and are most likely to be carried out by organized corporate interests.

The results of this study show large-scale reductions in dense forest and forest areas in Covalima (-88.39 sq.kms) and Ainaro (-80.61 sq.kms), which highlight the fact that over-exploitation occurred where there was greater abundance. Other evidence, independent of this study, also indicates that the forestry resources of East Timor were in relatively poor condition by 1974, having been subject to considerable exploitation for several hundred years during Portuguese rule, from the 16th century to 1974 (Rio, 1999; Aditjondro, 1994; Sandlund et al., 2001).

4.4.2. Competition for scarce resources

Often in the event of increasing land-use pressure from population growth, subsistence farmers with no recourse to supplementary income from non-agricultural sources will require additional patches of land to provide increasing yields to maintain their standard of living (Burgers et al., 2000). Metzner (1977) has identified this type of population imbalance in the Baucau–Viqueque region[2] and the impact of swidden agriculture on forest areas. Within the study area however, there is little evidence of the marks of swidden agriculture prior to the Indonesian period.

Notwithstanding this, the context of Indonesian rule and policies towards development of the province must be considered. Events of the period 1976–89 provided conditions leading to increased pressure on natural resources. It is argued here that demographic engineering, infrastructure development, population pressure and military presence all contributed to the changes in vegetation cover brought to light by our study.

In the 1980s, the central Indonesian Government in Jakarta implemented transmigration as its development policy in the eastern provinces. In troubled provinces, military deployment according to strategic geographical area, combined with transmigration, were considered necessary measures to integrate these provinces into the nation State (Tirtosudarmo, 2000). In East Timor, this policy lead to the colonization of border districts and the deployment of the military to support the civilian administration in the capital of Dili (Tirtosudarmo, 2000). Subsequent development efforts were concentrated in the more secure districts: Dili and areas west of the city. This interpretation is supported by Rio (1999), who states that the districts of Liquica, Alieu, Ermera, Bobonaro and Covalima all benefited most, in terms of aid and development, from the administration based in Dili.

The Indonesian administration considered that one of the keys to successful colonization of East

[2] This region lies immediately to the east of the study area.

Timor was the location of transmigration sites along the borders with West Timor to support military strategy (Tirtosudarmo, 2000). Transmigration sites were established in the border districts of Bobonaro and Covalima for Balinese,[3] Javanese and Timorese rice farmers (Aditjondro, 1994; Rio, 1999). Many of these farmers were settled onto rice farms that were previously owned by East Timorese, and not onto new areas within forests,[4] although some were indeed opened from scratch for the transmigration programme. According to Aditjondro (1994), this had two effects:

- The success which these transmigrants achieved in their endeavours quickly turned these border sites into economic growth areas attracting spontaneous migration from West Timor. The allocation of funds for the development of roads between West and East Timor facilitated migration into East Timor (Tirtosudarmo, 2000). This exacerbated the need to feed people, which further increased pressure on available land.
- The displacement of the original inhabitants and farmers from these transmigration sites to other locations also placed additional pressure on land.

One method used by the Indonesian authorities to deal with the continued resistance by the East Timorese people was to undertake so-called resettlement schemes. Essentially, this was the creation of new, ‘guided’ villages for people who were forcibly moved, or former collaborators with the resistance movement who had surrendered. Aditjondro (1994) describes the movement of people from mountain locations to new villages, which were established along roadsides or other areas where military control could be maintained. Approximately 18 of these villages were established within the districts of Covalima, Bobonaro, Dili, Ermera, Liquica, Alieu and Ainaro (Aditjondro, 1994). Rio (1999) argues that the lack of property rights, and the distance from traditional habitation grounds – causing people to be cut off from their habitual access to common property forest/woodlands that supply many daily household needs — in combination with overpopulation, resulted in the inability of

[3] Some locations near Maliana are clearly transmigration areas. One area in particular, called Tinubibi, was specifically for Balinese, with a Hindu shrine — one of two observed by the authors.

[4] For a description of how this was achieved see Aditjondro (1994).

East Timorese farmers to sustain themselves from their assigned plots. They therefore sought to develop more plots, which created pressure on areas where no formal tenure may have existed, such as forests and woodlands.

The preceding discussion has provided evidence that conditions in East Timor during the period of 1989–99 led to increasing and changing population pressure on the landscape within the study area. It is also argued, that in a country where 80% of the population relies on agriculture, [5] the pressure from the social and economic change discussed above was the cause of much of the vegetation decline and deforestation seen in woodland areas. The rural poor of East Timor generally work with hand tools, and for clearing, machetes are extensively used to cut timber. Apart from the fact that woodlands are the dominant vegetation type, the creation of new plots for growing maize and cassava would occur mainly in areas with the least vegetation coverage, given that these areas require less effort to clear. Hence, the highest levels of deforestation occurred in woodlands **-** in this case 14.6% between 1989 and 1999.

Conclusions

In the application of remote sensing/GIS technologies, Harwell (2000) explains that the ownership of discourse around the causes of change detected through studies (such as the present) can lead to an imbalanced view or can obfuscate alternative realities. The discussion of possible causes of identified landscape transformation in this article relies largely on the results of data interpretation and on published information on social and economic circumstances underlying these changes. What cannot

[5] For description of this sector see Rio (1999) and also Hill and Saldanha (2001).

be fully understood through the use of remote sensing/GIS technologies, however, is the ethnographic context and the history of change which colonialism had brought to East Timor (Harwell, 2000). This was an essential driver of environmental change, and the preceding discussion has merely illuminated a brief period of this history.

The use of remote sensing and image processing technology in this study should be considered a portion of a staged approach to understanding the environmental change in East Timor, an area that has been insufficiently studied to date. These tools clearly provide an insight that would normally be available only with more expensive ground research activities.

Specifically, this research has highlighted some significant findings, including:

- Location and extent of the reduction in foliage protected cover (FPC) and deforestation, revealing a pattern of decline leading to deforestation;
- Distribution of forest and woodland resources by district, revealing a declining trend in distribution of resources that provide a range of services for sustaining community livelihoods;
- A low stock of natural resource per capita, which reduces the opportunities for economic development; and
- An exploitation of resources in locations of abundance, and increasing competition for resources in locations where scarcity has occurred, or resulted due to population policies.

It is argued here that these findings could affect policies, not only for natural resources and environmental management, but also concerning economic development and poverty alleviation in a low-income developing country, such as East Timor.

The authors would like to stress that remotely sensed images do not provide a complete assessment of the issues discussed in this article, but should be treated as one of the datasets within an environmental database or geographic information system (GIS). Clearly, a number of data layers within a GIS are relatively static, such as topography, soils, rainfall distribution or roads. Vegetation, on the other hand is one of the more dynamic components and should be regularly updated or modelled, as a dynamic feature depending on management needs. Satellite data can form the basis for an operational mapping and monitoring system, as suggested by Hill et al. (1995). Hill et al. emphasize establishing a baseline (mapping) and subsequent monitoring as two essential first steps towards successful environmental management, policy development and implementation. Such an operational system requires standardized approaches in image processing, definition of consistent indicators for monitoring, standardized definitions and thematic interpretation (Hill et al., 1995). Once a base map of land cover/land use has been established, it is possible to detect change using such techniques as cross-correlation analysis (Koeln and Bissonnette, 2000).

If the social and economic development of the predominant agricultural sector in East Timor is to proceed in a sustainable manner, then the policies and programmes of the Government and aid organizations need to be cognizant of the historical influences on the country's natural resource base and its stock of capital. Furthermore, where there is a range of critical issues, as examined in this study, intervention and policies designed to alleviate pressure and encourage conservation and rehabilitation at the community scale need to be developed.

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Figure 1a. Regional map showing East Timor.

Map source: http://www.un.org/Depts/Cartographic/map/profile/timoreg.pdf.

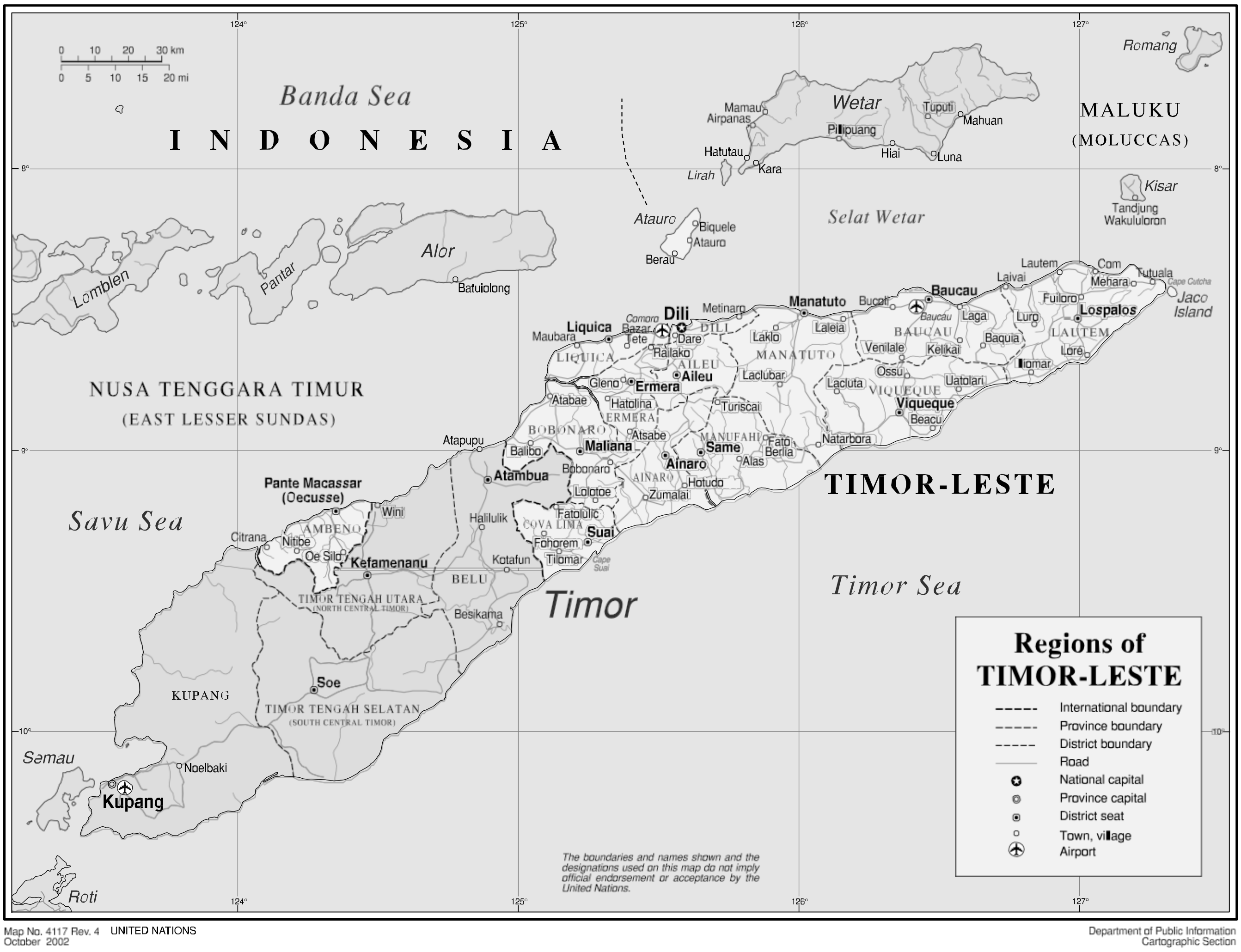

Figure 1b. Study area and district boundaries.

Map source: http://www.un.org/Depts/Cartographic/map/profile/timoreg.pdf.

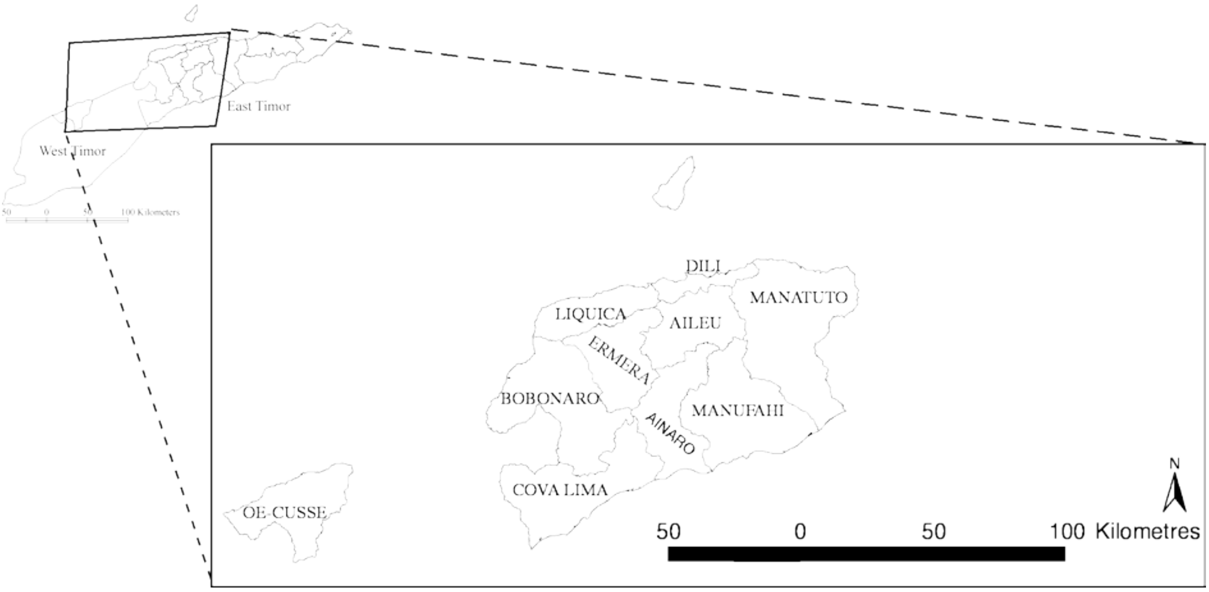

Figure 2. Example of cross-classification.

Matrix on the left represents sample data for forest cover in 1989; matrix in the middle, cover for 1999. Matrix on the right shows the results of cross-classification and effective legend. If a value of 0 represents no forest and a value of 1 represents forest, then the final image with a pixel value of 0|0 means that no forest was present in 1989 or 1999; 1|1, means that forest was present both in 1989 and 1999; 0|1, forest present in 1999 but not in 1989; and 1|0, forest present in 1989 but not in 1999.

0	1	1
1	1	0
0	1	1

0	1	1
0	1	0
1	1	1

0|0	1|1	1|1
1|0	1|1	0|0
0|1	1|1	1|1

Figure 3. Area of major vegetation classes per head of population and population in 1989. *Note*: * Asterisk indicates that results presented are only for part of that province, as sufficient data were not available (see Section 2).

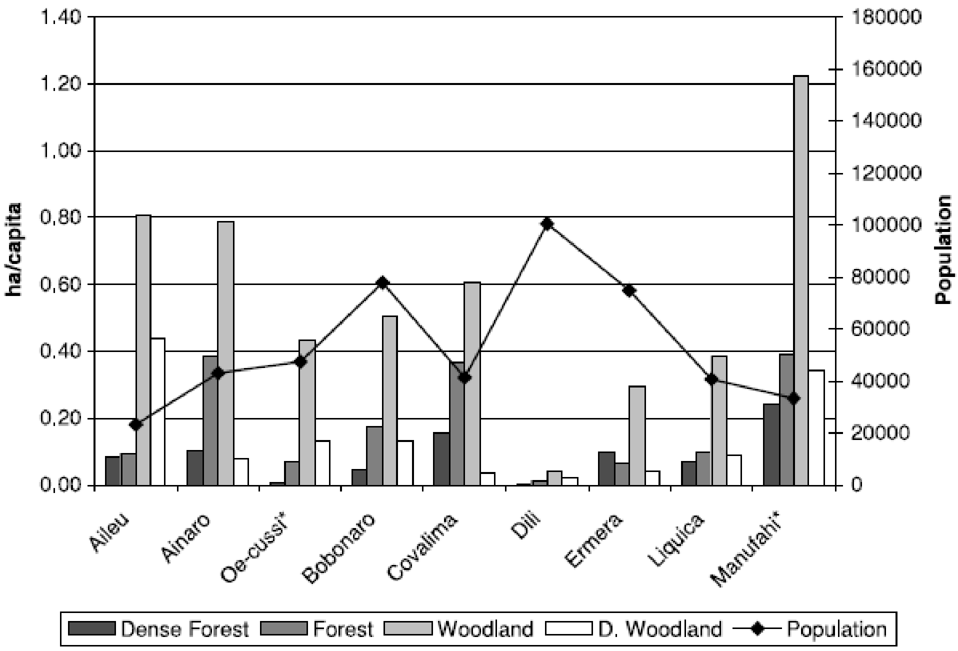

Figure 4. Area of major vegetation classes per head of population and population in 1999.
Note: * Asterisk indicates that results presented are only for part of that province, as sufficient data were not available (see Section 2).

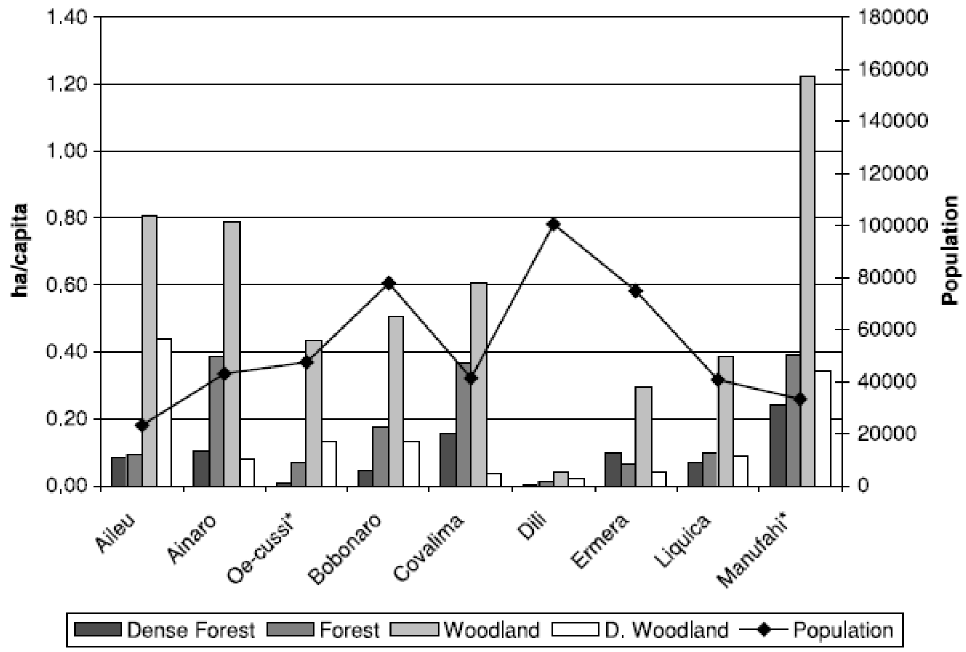

Table 1. Land and vegetation cover categories used in the study

Land cover categories	Vegetation cover types	Notes
Dense forest	Dense forest	Included all areas with a foliage protected cover (FPC) of 70% to 100%. Dominant species for each training site were not identified but included tropical forest species and palm species.
Forest	Mixed palm forest *Casuarina sp.* over shrubs *Acacia sp.* – mixed *E. urophylla*/mixed *Casuarina sp.* mixed	Included all areas with FPC of 30% to 70%. Training sites varied from predominantly palm species, *Eucalyptus urophylla* and *Casuarina equisetifolia.*
Plantation	Teak plantation Palm plantation	Included areas which were obvious plantation sites.
Mixed forest/coffee	*Casuarina sp.* over coffee *Albizia sp.* over coffee	Included areas where dominant shade trees are grown over coffee plants. Canopy density varied between 30% to 70%. Dominant species included, *Albizia falcataria*, and *Casuarina equisetifolia*.
Woodland	*E. platyphylla* Mixed species *E. urophylla* *E. urophylla*/mixed species	Included areas which could be described as tropical savannah woodlands. FPC ranged from 10% to 30% and in some instances at higher altitudes density for woodland species appears to increase. Two species of dominant woodland trees occur in East Timor, *Eucalyptus platyphylla* and *Eucalyptus urophylla*. In one case, *E. urophylla* occurred with *Casuarina equisetifolia* and some rainforest species.
Woodland (degraded)	*E. platyphylla* *Acacia sp.*	Same species composition as in woodland category, except degraded woodlands were considered to be subject to significant perturbations which reduced quality and vegetative cover of plant community. Includes areas subject to fire and/or grazing and/or coppicing for firewood collection.
Heath/shrubland	Northern coastal plain heath Southern coastal plain heath	Included all areas which had a predominant shrub or heath cover.
Agricultural land[a]	Included a range of sites from rice paddy through to maize fields, grassland, villages and gardens and alike.	
Other	Included sites that could not be classified into the above groupings including fire scar area, bare areas, river water and riverbeds.	

Note:

[a] As this study is concerned primarily with naturally occurring land cover, agricultural land was not considered, except for classification purposes

Table 2. Summary of change in land cover categories 1989-99

Cover categories	Area (km^2) 1989	Percent of area 1989	Area (km^2) 1999	Percent of area 1999
Dense forest	397.40	5	265.02	3
Forest	815.84	10	758.78	9
Plantation	253.31	3	421.43	5
Forest/coffee	463.82	6	575.05	7
Woodland	2,520.21	31	1,497.56	19
Woodland (degraded)	558.98	7	1,749.06	22
Heath/shrub	207.21	3	401.69	5
Agriculture	2,102.30	26	1,834.27	24
Other	698.04	9	514.25	6

Table 3. Summary of area and change in area between 1989 and 1999 of dense forest, forest and woodland in districts included in the study

	Dense forest				Forest				Woodland				Degraded woodland			
	Area (km^2) 1989	Area (km^2) 1999	Change (km^2)	Change (%)	Area (km^2) 1989	Area (km^2) 1999	Change (km^2)	Change (%)	Area (km^2) 1989	Area (km^2) 1999	Change (km^2)	Change (%)	Area (km^2) 1989	Area (km^2) 1999	Change (km^2)	Change (%)
Aileu	19.13	11.42	−7.72	−40.36	21.83	24.64	2.82	12.92	187.7	93.62	−94.05	−50.11	118.75	238.58	119.83	100.91
Ainaro	45.35	24.25	−21.09	−46.50	166.36	107.83	−58.53	−35.18	339.75	289.09	−50.65	−14.91	34.77	84.44	49.67	142.85
Oe-cusse	3.62	0.13	−3.49	−96.41	32.57	46.64	14.07	43.20	206.1	8.44	−197.64	−95.90	64.01	218.18	154.17	240.85
Bobonaro	36.49	17.03	−19.46	−53.33	136.79	153.74	16.95	12.39	392.29	143.70	−248.58	−63.37	101.94	431.44	329.5	323.23
Covalima	63.53	12.18	−51.35	−80.83	152.59	115.55	−37.04	−24.27	250.99	201.92	−49.07	−19.55	18.97	83.52	64.55	340.27
Dili	1.27	0.53	−0.47	−37.01	13.40	12.29	−1.11	−8.28	39.73	9.01	−30.72	−77.32	22.74	82.39	59.65	262.31
Ermera	72.31	41.06	−31.25	−43.22	47.61	60.14	12.53	26.32	219.81	120.84	−98.97	−45.03	32.83	122.09	89.26	271.89
Liquica	27.52	10.19	−17.33	−62.97	39.37	59.11	19.75	50.17	156.8	67.82	−88.96	−56.73	38.11	101.81	63.7	167.15
Manatuto	43.51	51.50	7.99	18.36	61.18	59.90	−1.28	−2.09	294.31	168.12	−126.19	−42.88	83.6	258.52	174.92	209.23
Manufahi	81.35	98.01	16.66	20.48	129.79	103.72	−26.07	−20.09	408.13	387.23	−20.90	−5.12	40.03	117.35	77.32	193.16

Table 4. Percentage change in area of deforestation and area reduction in folio protected cover (FPC) between 1989 and 1999

Vegetation cover type	Deforestation (%)	Reduction in FPC (%)
Dense forest	8.7	23.7
Forest	3.9	3.1
Woodland	14.6	26.0

Note: Total figures are not inclusive of other vegetation cover types such as degraded woodland and forest/coffee.

Table 5. Mean patch size for selected districts in East Timor 1989–99

District	Mean patch size (ha)		Number of patches	
	1989	**1999**	**1989**	**1999**
Dili	0.64	0.40	2,417	3,285
Covalima	1.13	0.63	22,210	22,865
Bobonaro	0.62	0.54	28,976	32,963
Manufahi	0.61	0.57	35,855	37,481