ABSTRACT

Title of Document: ENDANGERED DRY DECIDUOUS FORESTS OF UPPER MYANMAR (BURMA): A MULTI-SCALE APPROACH FOR RESEARCH AND CONSERVATION

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Tropical dry forests are critically endangered and largely unprotected ecosystem. I used a multi-scale research approach to study Upper Myanmar's dry deciduous forests. At the broad scale I assessed how well existing land cover data can be used to map and monitor dry forests, and estimated the extent, distribution, and level of protection of these forests. At the landscape level I assessed spatial and temporal dynamics of deforestation in and around a dry forest protected area, Chatthin Wildlife Sanctuary (CWS), investigated land use pressures driving these changes, and evaluated effectiveness of protection efforts within the sanctuary. At the local scale I studied the degree to which people rely on dry forests for subsistence and the socioeconomic variables correlated with dependence on forest products.

Using MODerate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data to delineate remaining dry deciduous forests, I

found that only 24,000 km^2 of this forest type remain in Upper Myanmar—only 4% inside protected areas. At 81% accuracy, this map scored higher than existing global and regional land cover classifications for predicting dry forest.

Employing satellite images covering the landscape in and around CWS (Landsat MSS, TM, ETM+ and ASTER) between the years 1973-2005 , I found that 62% of forest was lost (1.93% annual rate) primarily from agricultural conversion and hydroelectric development. Sanctuary protection has been effective in slowing decline: loss rates inside CWS were 0.49% annually (16% total). However, forest inside the sanctuary is still declining at a rate above the global average and shows evidence of impact from forest product extraction around the boundaries.

Based on interviews with 784 people living in 28 subsistence-based agricultural communities located in and around CWS, I found virtually all survey respondents depended on CWS for food, medicine, housing materials, and, above all, fuelwood. Poverty and socioeconomic limitations drive extractive activities. While CWS has been effective in slowing deforestation rates, alternative use strategies that benefit people will improve prospects for long-term conservation in the area. My results demonstrate that a multi-scaled research approach is essential for understanding the drivers impacting the rapidly-declining dry forests of Upper Myanmar.

ENDANGERED DRY DECIDUOUS FORESTS OF UPPER MYANMAR (BURMA): A MULTI-SCALE APPROACH FOR RESEARCH AND CONSERVATION

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Dedication

For my partner Chris – thanks for everything

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Chapter 1: Introduction

Tropical dry forests constitute one of the most threatened and least protected tropical ecosystems. Yet little information exists on their conservation status. Tropical research and conservation are frequently focused on other tropical forest types, such as the rain forests of the Amazon. My research addresses conservation issues focusing on dry deciduous forests—a dry forest ecosystem especially threatened in Southeast Asia. Lack of baseline data on dry deciduous forests makes it difficult to develop effective conservation strategies at continental or even national scales. This is particularly true in Myanmar (Burma), a country that is geographically and politically isolated and where only limited biological research has been conducted. Taking a multi-scale approach, I have studied the status of these forests in Upper Myanmar, the drivers of land use change that threaten dry forests, the effectiveness of traditional protected area conservation for preserving dry deciduous forests, and the importance of these ecosystems to rural human populations.

Research Goals and Objectives

The goal of this study is to investigate the patterns and drivers of deforestation within tropical dry forests of Upper Myanmar to better inform strategies for their conservation. The objectives of this study are to evaluate whether tropical dry forest can be mapped accurately from existing land cover data sets, analyze the land cover change patterns in and around a dry forest protected area in Myanmar, and assess the underlying socioeconomic factors driving extraction inside the protected area. I have used a combination of techniques to study the dry forests of Myanmar and selected Chatthin Wildlife Sanctuary (CWS) for case studies at the landscape and local level. Major questions I address are:

- What are the extent, distribution, and protection levels of the remaining dry forests of Upper Myanmar?
- Can existing land cover data be used to map these forests consistently, and be used to monitor their extent and potential decline at a regional scale?
- What factors lead to the decline of theses forests at regional, landscape, and local levels, and can remote sensing be used to identify and assess these factors at a landscape scale?
- How much do local people rely on dry forests for subsistence, and is this reliance correlated with socioeconomic status?
- Why do dry forests seem to be so susceptible to degradation by people and can traditional protected area practices effectively conserve them?

These questions can only be addressed with a combination of field studies, remote sensing, and spatial analysis. Detailed data collected from key sites on the ground are needed to develop a better understanding of the human-induced drivers of change affecting dry forest ecosystems. Each of these steps in the analysis provides critical data leading to a more comprehensive understanding of the factors reducing the last of the world's tropical dry forests.

Background

Anthropogenic global changes are among the most pressing environmental problems of the 21st century and pose significant threats to global biodiversity (Vitousek 1994; Sala et al. 2000; Thuiller et al. 2006; Wilby et al. 2006). Major global changes such as dramatically increased levels of atmospheric carbon dioxide (Woodwell et al. 1983; Houghton & Hackler 2000; Houghton et al. 2002), altered global climate patterns (Arendt et al. 2000; Clark et al. 2002), introduction of invasive species (Sala et al. 2000) and broad-scale land use/land cover changes (Novacek & Cleland 2001; Brook et al. 2003) may significantly impact biodiversity (Vitousek 1994; Sala et al. 2000; Novacek & Cleland 2001; Brooks et al. 2002; Thuiller et al. 2006). Land use/land cover change is predicted to have the largest effect on the world's ecosystems and biodiversity (Vitousek 1994; Sala et al. 2000). Agricultural conversion, timber extraction, and urban development are so extensive that it is estimated humans have transformed between one-third and one-half of the terrestrial surfaces of the Earth (Vitousek et al. 1997).

Deforestation is among the best documented broad-scale global changes (Skole & Tucker 1993; FAO 2001; Achard et al. 2002; Guild et al. 2004; Vina 2004). In addition to its impacts on biodiversity, deforestation affects carbon sequestration, hydrological cycles, and climate change (Palm et al. 1986; Houghton & Hackler 1999; Bruijnzeel 2004). The loss of Amazonian rain forest is well documented and widely acknowledged; probably it is one of the environmental issues best known to the general public. However, significant and dramatic losses in other forest ecosystems, such as temperate and boreal forests, are much less publicized and not widely known. Seasonally dry tropical forests in particular receive relatively less attention from scientists and the public compared to that given to tropical rain forests (Mooney et al. 1995; Sanchez-Azofeifa et al. 2005).

Threats to Dry Forests

Tropical dry forests may be receiving less attention from scientists and the public because they have been impacted by humans for a much longer time period (thousands of years) and at a broader spatial scale than rain forests. By comparison, broad-scale deforestation in rain forests occurring in areas such as the Amazon and Congo Basin is a much more recent phenomenon. However, tropical dry forests are much more threatened and less protected than rain forests (Janzen 1988; DeFries et al. 2005; Sanchez-Azofeifa et al. 2005). The World Wildlife Fund's (WWF) ecoregional assessment for the Indo-Pacific Region reported that "dry forest ecoregions are in the worst condition of any in the region", with 50% considered critical or endangered (Wikramanayake et al. 2002:101). These authors also report that the tropical and subtropical dry broadleaf forest biome has the highest percentage of habitat loss (73%) and estimate a loss of 1,613,400 km^2 from original cover. Like their wet forest counterparts, tropical dry forests are being depleted by conversion to agriculture, forest product extraction, and commercial logging.

For thousands of years, tropical dry forests have been used more extensively by humans than rain forests. The climate and structure of dry forest make it more desirable for timber harvesting, but dry forests also often harbor many valuable tree species. For example, dry deciduous forests—a specific type of dry forests traditionally found throughout Southeast Asia—are economically important because of the considerable amount of valuable timber they contain. These timber species include teak (*Tectona grandis*) and paduak (*Pterocarpus macrocarpus*) (Brunner et al. 1998).

Other environmental features of dry forest ecosystems often not found in wetter tropical forest types make them particularly easy to colonize and convert to agriculture (Murphy & Lugo 1986). The dryness of these ecosystems makes them easier to convert to agriculture with the use of fire, which also increases the seasonal growth of some plants, such as grasses for livestock. Dry forests frequently are found in relatively flat areas that facilitate farming and are preferred by local farmers over more hilly forest regions (Bullock et al. 1995). The dry season helps keep insect and weed populations down, and the lower precipitation per area results in reduced leaching and as a consequence, more fertile soils. The climate together with lower insect densities makes them more favorable for maintaining livestock (Murphy & Lugo 1986). Much of the dry forest around the globe has already been converted to agriculture. What remains often consists of fragmented and isolated patches amidst agricultural development.

Importance of Dry Forests for Rural Populations and Global Biodiversity

In most regions, tropical dry forests are considered essential resources for local people, providing a wide array of services and goods (Stott 1990; Murali et al. 1996). Their utility and importance in supporting the livelihood of rural human populations likely has contributed significantly to their decline. Today, most of the remaining dry forests are surrounded by high densities of humans (Murphy & Lugo 1986) and are never far from the next village (Rundel & Boonpragob 1995; Janzen 1996). It is estimated that globally as much as 80% of the wood cut in tropical dry forests is used as fuelwood for cooking and heating (Murphy & Lugo 1986). The range of important dry forest products and services is diverse and includes medicinal plants, thatch and wood for homes, foods such as fruits, nuts, mushrooms, wild vegetables and game, and other household products (Stott 1990; Murali et al. 1996).

Tropical dry forests not only provide essential resources to people; their unique and challenging environmental conditions have resulted in the evolution of highly specialized organisms and life history strategies. These ecosystems stand out not for having the highest levels of diversity, but for their structural organization and adaptations for surviving stress and disturbance (Bullock et al. 1995). Because of these factors, tropical dry forests provide habitats for many endangered species, and possess greater life form diversity and unique ecological and physiological adaptations not found in other ecosystems (Stott 1990; Bullock et al. 1995; Gentry 1995; Medina 1995). While tropical dry forests have lower levels of biomass in comparison to wet forests due to their limited growing season, typically they have larger proportions of biomass underground and smaller aboveground forms.

Rain forests may have higher levels of vertebrate diversity, but tropical dry forests are important in the conservation and maintenance of global biodiversity. They often represent strongholds for preserving endemic species (Mares 1992). The number of these endemic species continues to rise as new species are being discovered (Ceballos 1995). Loss of these ecosystems and their endemics would significantly reduce the conservation of globally representative samples of ecosystems and species. For example, tropical dry forests often support diverse bird assemblages. There are an estimated 52 bird species found in Myanmar's (Burma's) dry dipterocarp forests (King & Rappole 2001) including at least three endemic bird species: the white-throated babbler (*Turdoides gularis)*, the hooded treepie (*Crypsirina cucullata*), and the Burmese bushlark (*Mirafra microptera*). The same habitats also support the critically endangered Burmese star tortoise (*Geochelone platynota*) (Tordoff et al. 2005) and several species of snake (Leviton et al. 2003).

Tropical dry forests are also strongholds for large mammal species. Field ecology research has shown that the dry forests of Myanmar's central dry zone are vital to the survival of the endangered Eld's deer (McShea et al. 1999, 2001). The endangered primate species, the hoolock gibbon (*Bunipithecus hoolock*) and capped-leaf monkey (*Trachypithecus pileatus*), as well as other endangered species including gaur (*Bos gaurus*), banteng (*Bos javanicus*), elephant (*Elephas maximus*) and tiger (*Panthera tigris*) all use tropical dry forest habitat (Tordoff et al. 2005).

Eisenberg (1980) found that dry forests support higher biomass of mammalian herbivores than rain forests. In South Asia, dry forest habitats typically sustain higher elephant densities, 3 to 5 elephants/km^2, compared to only 1 elephant/km^2 in rain forests (Sukumar 2003). Though tropical rain forests are higher in biomass than dry forests, fewer of their plants are edible for elephants and many contain poisonous chemicals. The food in rain forests tends to be of lower quality and more highly dispersed, requiring elephants to expend more energy in foraging. As a result elephants can have higher fecundity in dry forests, increasing at a maximum rate of up to 4% per year, compared to only 1% in rain forests (Sukumar 2003).

Dry Forests, Protected Areas, and People

Only a small proportion of the world's remaining tropical dry forest is protected (Janzen 1988; Sanchez-Azofeifa et al. 2005; Miles et al. 2006). Higher human population densities in close proximity to remaining tropical dry forests bring about higher extraction pressures than what is typically found in wet tropical forests (Bullock et al. 1995). To compound the problem, dry forest conservation via traditional protected area establishment and management often is not effective. Especially in developing countries, protected areas frequently are not well managed, or are simply "paper parks" with no staff or protection efforts. Even if there is a motivated and active staff, they often don't have access to appropriate technology, infrastructure and technical capacity. Funds for park staff and management almost always are insufficient, leading to low motivation or even causing some park staff to resort to extracting resources from the park to supplement their income.

Enforcing park boundaries and preventing extraction of forest products can be particularly challenging in areas of high human population and subsistence agriculture (Botteron 2001). Villagers consider forest areas common property, leading to an iteration of the "tragedy of the commons" phenomenon, namely the increased likelihood of a natural resource being overused if many people have equal claim to it and none of the individuals feel they can personally benefit from preserving it over time (Hardin 1968).

The negative effects of human impact on ecosystems have prompted many nature advocates to suggest that parks must remain free of human use (Noss et al. 1999). Conservation biologists frequently have claimed that the presence of people is not compatible with conservation efforts in tropical forests (Redford 1992; Redford &

Stearman 1993; Peres 1994; Peres & Terborgh 1995). In developing countries a large section of the population may depend on natural ecosystems for its subsistence and if these resources are taken away people face increased hardships (Reddy & Chakravarty 1999). This is especially true in tropical forest regions, where the lives and livelihood of rural people are closely tied to the forest. This is not a new phenomenon. Extraction and trade of non-timber forest products dates back over 2000 years, and most humans lived as hunter-gatherers for 99.9% of human history (Stiles 1994).

Given this wider context, the idea of untouched wilderness that needs to be protected from outside threats by humans can be difficult to defend against the needs of people who have long been relying on forest products to supplement food, provide fuelwood for cooking, medicine and materials for shelter. What has changed is not the degree to which individuals depend on forests but the number of people that do so. Rapid human population growth has exacerbated the consequences of use. In addition, demands for consumer products from industrial nations often drive unsustainable extraction of forest products, both timber and non-timber. If such patterns continue at current rates and levels of intensity, resources will be depleted in the near future and local people will lose their valued resources. Ecosystems provide services necessary for the survival and health of humans, including food, fresh water, fuel, detoxification systems, climate regulation, as well as cultural and recreational services (WHO 2005). The loss of ecosystem services, often neither quantified nor comprehensively described, may have significant, unrecognized effects on human health and livelihood.

To develop effective strategies for mitigating extraction impacts, we need to understand more about the people concerned, and about how they are using products from the specific forests under consideration. Tropical dry forests provide a wide range of ecosystem services, including watershed stabilization, provision of dependable water supplies, and soil stabilization. The last is particularly important in dry forest regions that are partially converted to agriculture because soil stabilization helps to maintain soil quality, which in turn allows for good harvests and increased food availability (Daily 1996). The loss of these dry forest services will have an impact on the entire rural population across a region, while the loss of the dry forest products and resources often impact the poorer segments of the population, i.e. individuals or families with fewest means, who depend on the forest for basic needs and income generation.

Mapping Tropical Dry Forests

Little comprehensive information exists on the extent and status of remaining tropical dry forests, and the information that does exist is often contradictory and confusing. For example, past and current estimates of the extent of remaining dry forests are conflicting. Estimates for the late 1980s, provided in the Conservation Atlas for Tropical Forests, report approximately 452,000 km^2 for Southeast Asia (Collins et al. 1991). This number is substantially lower than the estimate published in WWF's late 1990s ecoregions assessment, which placed tropical dry forests at close to 600,000 km^2 (Wikramanayake et al. 2002). Taken together the two estimates would portray a 25% increase over the intervening decade, an unlikely supposition considering the rapidly increasing human populations in Southeast Asia during the same time period. This and other examples of troubling discrepancies found when comparing existing dry forest estimates point to the lack of solid, detailed information on the status of Asia's tropical dry forests and demonstrate the need to acquire better data over the long-term to help detect dry forest declines and approximate their extent.

Regional scale discrepancies in tropical dry forest estimates include an example concerning Myanmar's dry forest coverage. Based on a map created by MacKinnon (1996), Brunner et al. (1998) estimated that Myanmar's dry deciduous forest had declined by over 83%; while originally covering 31,388 km^2, only 5,407 km^2 supposedly remained in 1996. The original MacKinnon map is based on Advanced Very High Resolution Radiometer (AVHRR) imagery, which has a spatial resolution of 1 km. However, an analysis based on Landsat Thematic Mapper (TM) imagery, with a finer spatial resolution of 30 m, estimates 8,691 km^2 covering a section of Myanmar's central dry zone alone (McShea et al. 1999). This estimate is 37% higher—in total km^2—than Brunner et al., despite the fact that it covers a smaller area of the country than their study.

Remote Sensing Tools

The last two decades have seen an explosion in the development and utility of geospatial analysis techniques for the delineation, monitoring, and assessment of the natural environment and of how it is changing. Satellite remote sensing has become a key resource for conservation and natural resource management, providing highly accurate data for mapping ecosystems (Coppin & Bauer 1996; Chauvaud et al. 1998; DeFries et al. 1998; Hansen et al. 2000; Treitz & Howarth 2000; Lefsky et al. 2002). The number of satellite sensors available for analysis has increased dramatically, along with computational tools, hardware, and software used to analyze the data. The power and availability of computer workstations have also increased and further accelerated this expansion (Leimgruber et al. 2005).

Using satellite imagery for mapping forest extent and losses has become a standard tool in the toolbox not only of researchers and geographers, but also of land managers and environmental organizations interested in natural resource conservation (Verbyla 1995; Wilkie 1996; Uhl et al. 1997). These tools have been used successfully to demonstrate the devastating speed and extent with which we are losing tropical rain forests (Skole & Tucker 1993; Achard et al. 2002; Curran et al. 2004; Linkie & Smith 2004). However, little information is provided on deforestation of tropical dry forests. This may be partly explained by the limitations of remote sensing. It is often difficult to distinguish between ecosystems possessing a fair amount of spatial heterogeneity in their canopy structure via remote sensing analysis (Jensen 1996). Dry forests are a classical example of this type of spatially heterogenous ecosystem. These forests also have pronounced seasonality and interannual variability of productivity resulting from climate variations, making it a challenge to distinguish changes related to climatic variations from those resulting from human impacts.

Tropical dry forests are often characterized by an open canopy and little understory. The spatial heterogeneity in reflectance across the electromagnetic spectrum presents significant problems for mapping these ecosystems. An additional problem for assessing any set of forest resources at differing spatial and administrative scales are the discrepancies in how various interest groups or individuals define forests (Lund 1999; Matthew 2003). Most ecological definitions are based on tree density, canopy closure, and tree height. Yet a study of basic terminology used internationally for conservation tallied over 130 definitions for forest from just 30 countries (Lund 1999). These 130 definitions sorted out into three different types: administrative—areas officially named as forest; land cover—areas with a certain percentage of tree or canopy cover; and land use—areas that can be used for timber and are not being used for something else. How a forest is defined can make a difference in results. This is true of dry forests, which represent a transition zone between closed rain forests and scrubland and grassland.

The thresholds for defining these forest ecosystems vary with location and plant association, and also with cultural and economic perceptions of what represents a forest. Published definitions of dry forest ecosystems in Asia range from forests with primarily deciduous tree species and less than 1,000 mm precipitation/year (Ruangpanit 1995), to describing them as evergreen and deciduous forest with precipitation ranging up to 2,300 mm/year (Rundel & Boonpragrob 1995). A review of descriptions of dry forest in Latin America, Africa, and Thailand finds that seasonality of rainfall is the common factor throughout (Mooney et al. 1995).

Dry Forests of Myanmar

A large proportion of the studies on tropical forests is based on neotropical regions rather than Asian forests (Sanchez-Azofeifa et al. 2005). Comparatively, the ecology and distribution of the dry forests of Southeast Asia are not well studied. This is particularly a problem in Myanmar, where the country's geographic and political isolation have taken a toll on research opportunities and studies. As a result, very little research has been done in Myanmar and there is a great need for baseline data, particularly on land use/land cover change. Of late, western scientific and conservation organizations have become increasingly interested in the country because of its high levels of biodiversity and broad range of ecosystem types. Myanmar crosses three major biogeographic regions, harbors a large number of endemic species, and is a key biodiversity stronghold in the Indo-Pacific region (Wikramanayake et al. 2002). Through field research in various parts of the country, my colleagues and I at the Smithsonian's Conservation and Research Center (CRC) have accumulated extensive firsthand knowledge about Myanmar's forest ecosystems and their associated fauna (McShea et al. 1999; Myint Aung et al. 2004; Koy et al. 2005; Leimgruber et al. 2006). This knowledge has been correlated with remote sensing studies, and we now know that Myanmar has some of the best preserved forest cover of mainland Southeast Asia and also maintains large patches of tropical dry forests (Koy et al. 2005; Leimgruber et al. 2006). Though 2.26% (15,068 km^2) of the country has been designated as protected (NWCD 1999), many of the parks are not adequately staffed or funded (Rao et al. 2002; Myint Aung 2006). Within Myanmar there are protected and unprotected dry forest areas that can be studied comparatively to assess the effectiveness of protection for the conservation of these forests.

One such area is Chatthin Wildlife Sanctuary (CWS), located at the edge of the central dry zone in Upper Myanmar. Scientists from the Smithsonian's CRC have been conducting joint research and conservation projects at CWS since the early 1990s (Wemmer et al. 2004) and I have been working there for the past five years. CWS consists mainly of tropical dry deciduous forest, known in Myanmar as "Indaing". The sanctuary is surrounded by densely populated agricultural areas and provides a unique opportunity to investigate: a) how people are using forest products extracted from CWS; b) which groups in the local population are more dependent on forest products; c) who is doing the collecting; and d) what is being collected. CWS also offers the opportunity to study spatial patterns in forest use.

As a result, in large part, of the research and management support work carried out by Smithsonian scientists, the sanctuary also has the best trained staff in the country. The park warden, rangers and base camp staff are enthusiastic about research projects and they have been critical to the success of my project. For all of the reasons enumerated in the preceding paragraphs, Myanmar's CWS provides an excellent location for a case study on the spatial and temporal dynamics that affect dry forests at local scales and how these might be linked to people's use of forest resources. Though my project focused on a single region in a single Southeast Asian country, I hope to demonstrate that I have developed techniques that will be valid for studying dry forests at a regional scale. Similarly, I hope that my results will provide insights for the conservation of these ecosystems, both in Myanmar and in the region.

Dissertation Organization

This research is organized moving from broad scale to finer scale analyses. Chapters 2 through 4 have been written so that they may stand alone for publication in separate journals; each has an introduction, methods, results, and discussion. Chapter 4 has already been submitted to Ambio for review. In Chapter 2 I assessed the extent of dry forests for Upper Myanmar using existing global and regional land cover data sets. In addition, I utilized seasonal MODIS NDVI 16-day composite data to create a new map distinguishing dry deciduous forest from all other ecosystems in Upper Myanmar. The chapter includes an extensive accuracy assessment of the dry deciduous dry forest map and existing land cover classifications, and assessment of the protection status of the Myanmar's remaining tropical dry forests. In Chapter 3 I analyzed the spatial and temporal dynamics of land cover changes from 1973 through 2005 in and around Chatthin Wildlife Sanctuary (CWS), which was determined through the analysis in Chapter 2 to be the largest remaining protected dry deciduous forest area in Myanmar. Through classification of 5 satellite images I analyzed rates of deforestation, assessed effectiveness of the protection of CWS, and identified drivers of land use change in the study area. In Chapter 4 I investigated the use of forest products by local communities living in and around CWS, to understand how people are using the sanctuary forest and what socioeconomic factors drive dependence on forest products.

Chapter 2: Using MODIS NDVI Data Products to Map Dry Deciduous Forests in Upper Myanmar (Burma)

ABSTRACT

Dry deciduous forests are considered to be one of the most threatened and least protected tropical ecosystems. Yet there are few reliable maps for monitoring these forests, making it difficult to develop conservation strategies for this ecosystem and its associated biodiversity. Focusing on Upper Myanmar (Burma), I created dry forest maps based on existing global and regional land cover data sets. I also used seasonal 250-m MODIS NDVI 16-day composite data to produce a forest cover map distinguishing dry deciduous forest from other ecosystems for Upper Myanmar (Burma). The overall accuracy of my dry deciduous forest map is 81% when compared to 188 independent validation samples. My map demonstrates a higher accuracy for dry deciduous forest than presently existing global and regional land cover classifications made using the same 188 samples. Only 24,000 km^2 of dry deciduous forest remains in Myanmar; only 4% of this is protected. Even protected forest areas contain very little dry deciduous forest, which altogether, inside and outside protected areas, cover only about 7% of all protected areas in the country. Remaining dry deciduous forests are under increasing extraction and conversion pressures as human population increases. Improved management of already protected dry deciduous forest, along with the creation of new protected areas is urgently needed.

INTRODUCTION

Dry forests are considered to be one of the most threatened tropical ecosystems globally (Janzen 1988; Wikramanayake et al. 2002; Miles et al. 2006). These forests are particularly rare in Southeast Asia, where only a small proportion of their total area is under legal protection (Miles et al. 2006). Frequently, dry forests are surrounded by areas with high human population densities (Murphy & Lugo 1986) and as a result they are subjected to higher levels of human impact than rain forests (Bunyavejchewin 1982; Murphy & Lugo 1986; Janzen 1988; Bullock et al. 1995; Maass 1995). Almost all remaining dry forests are under threat from deforestation, climate change, agricultural conversion or other human-caused threats (Miles et al. 2006). However, current information on their extent and on the rate at which they are disappearing is limited to global data sets (Miles et al. 2006) and is generally not widely available at finer resolution.

Despite recognition that tropical dry forests are rare, highly threatened and poorly protected, there are few reliable maps (but see Miles et al. 2006) or established means of monitoring, making it difficult to develop strategies for conserving these forests. Analysts for the United Nations Forest and Agriculture Organization’s (FAO) found that dry forests were underrepresented in remote sensing analyses, and area estimates for subtropical and tropical dry forests had to be adjusted by a higher correction factor than other forest types (FAO 2001). Traditional remote sensing methods often do not perform well in the mapping of open canopy forests such as dry forests (Jensen 1996). These forests are difficult to separate from other mixed and open habitat types including shrubland or even degraded forests (Grainger 1999).

Remote sensing provides a vast set of tools and opportunities for assessing land cover, and specifically forest cover and deforestation (Skole et al. 1993; DeFries et al. 1998; DeFries et al. 2000; Tucker et al. 2000; Curran et al. 2004; Linkie et al. 2004; Maselli et al. 2004). Using these tools, researchers have produced a number of regional and global land cover classification data sets (DeFries et al. 1998; Hansen et al. 2000; Loveland et al. 2000; Vogelmann et al. 2001; Cihlar 2003; Bartholome & Belward 2005). These data sets are regularly used for studies on the extent, location and condition of different ecosystem types and for other ecological research (Sanderson 2002; Leimgruber et al. 2003; Hubener et al. 2005; Dinerstein et al. 2006) and may represent a first step for analyzing the extent of remaining tropical dry forests.

Myanmar (Burma) is one of the most forested countries in Southeast Asia (Leimgruber et al. 2006) and supports large areas of dry deciduous forests—one of the most endangered dry forest ecosystems in the country (Tordoff et al. 2005). Dry deciduous forests are characterized by a distinct leaf-off period at the height of the dry season and feature many dry- and fire-adapted tree species such as *Dipterocarpus tuberculatus*, *Shorea obtusa*, *Terminalia tomentosa* and *Melanorrhoea usitata* (McShea et al. 1999; Koy et al. 2005). Trees are widely spaced and interspersed with large grassy patches, resulting in open canopies (>30%) and open understories (Koy et al. 2005). The openness is maintained by regularly occurring fires (McShea et al. 1999).

Focusing on Upper Myanmar, I created dry forest maps based on existing global and regional land cover data sets. I compared these data sets to determine their consistency in delineating dry forests and utilized higher resolution satellite imagery to determine their accuracy. I also produced a generalized dry deciduous forest map, by analyzing MODerate-resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data (Huete et al. 2002). MODIS NDVI is a 16-day composite data set at 250 m spatial resolution and is freely available via the Internet. I did not attempt to produce a land cover map for all different forest types, but focused on distinguishing dry deciduous forest from all other ecosystems. Using these data I addressed the following questions:

1) Can global and regional land cover data sets be used to assess dry forests for Upper Myanmar?
2) How accurate are dry forest maps based on these data?
3) How does a generalized MODIS NDVI map of dry deciduous forests compare to dry forest mapped by existing broad scale land cover data sets?
4) How much dry deciduous forest is remaining in Upper Myanmar and where is it found?
5) How much of these remaining dry deciduous forests is under protection?

METHODS

Study Area

My study covered 327,394 km^2 of Upper Myanmar; over half of the country (Figure 2.1). The analysis was based on the MODIS NDVI tile covering Upper Myanmar, all of Bangladesh, and parts of India and China. I clipped the tile to include only area overlapping Myanmar. The study area includes the majority of dry deciduous forest found in the country. It includes most of the central dry zone, the region supporting 80%

of the country's 42.5 million people. In the past this zone was primarily forest (Kurz 1877; Stamp 1925). Now, however, the area has largely been converted to agriculture (Leimgruber et al. 2006; see Chapter 3 for case study). At the edges of the horseshoe-shaped dry zone the land transitions into hill country, the foothills of the Himalayas extending in two long mountain chains from the north of Myanmar to the south. The country has a monsoon climatic system with 3 seasons, including the rainy season (~0.4 m rainfall annually), the cool-dry season, and hot-dry season (Myint Aung et al. 2004). The rainy season lasts from June to September and the leaves start to fall near the end of the cool-dry season (October to January). The surrounding hill country produces a distinct rain shadow in the central dry zone, although rainfall during the rainy season can still be very high.

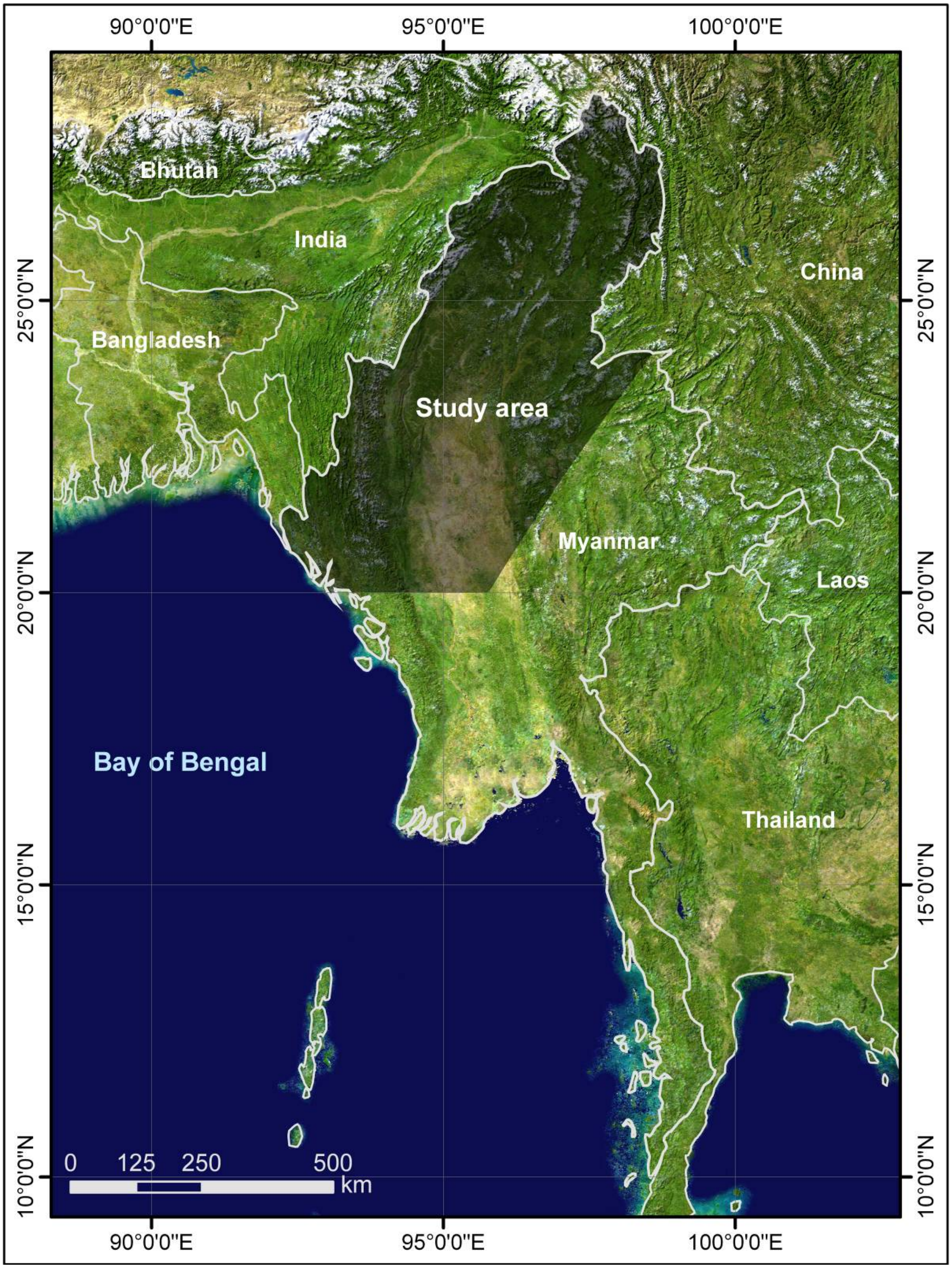

Figure 2.1. Study area for mapping dry deciduous forests in Upper Myanmar.

Dry Forest Classification

My analysis is based on seasonal NDVI data produced from 250 m, 16-day MODIS composites. MODIS products were developed to deliver standardized, reliable vegetation data with global coverage and high spatial and temporal resolution for monitoring purposes (Running et al. 1994, available from (http://glcf.umiacs.umd.edu/data/modis/ndvi). NDVI is calculated as the ratio of reflectance in the near infrared (NIR) and visible red bands normalized with the formula (NIR-red/NIR+red) (Tucker 1979). This index is useful for measuring seasonal and inter-annual variations in vegetation by reducing data noise from shadows, interference from the atmosphere, and variations in topography (Huete et al. 2002).

The 250 m MODIS NDVI product is available in tiles encompassing roughly 1,200 km by 1,200 km and is composed of 16 days of observations. Composites are based on the MODIS Vegetation Index (VI) algorithm, which filters pixel observations to obtain only the higher quality, near-nadir, and cloudless data (van Leeuwen et al. 1999, Huete et al. 2002). Depending on the number of observations that remain after filtering, one of three possible techniques are used to produce the best pixel value to represent a particular area. These techniques include the bidirectional reflectance distribution function composite (BRDF-C), the constrained-view angle-maximum composite (CV-MVC), and the maximum value composite (MVC) (Huete et al. 2002). The BRDF requires 5 high quality observations, from which nadir equivalent band reflectance values are interpolated. The CV-MVC is based selection of the pixels with the two highest NDVI values; then the one closest to nadir is used. If there are no high quality pixels remaining after the filter, the MVC approach is used to select the pixel with the highest

NDVI. The results are the best quality data available from the 16-day period (closer to nadir, fewer clouds and haze effects) (Huete et al. 2002).

For the mapping I acquired two NDVI tiles representing the wet season (1 November 2003) and the dry season (7 April 2003) respectively. Within this tile coverage, I limited my analysis to the portion covering Myanmar because I have extensive ground knowledge of this region (Leimgruber et al. 2006).

Dry deciduous forests have a distinct seasonal phenology, which distinguishes them from the evergreen forests often found in close proximity. To take advantage of this seasonal phenology for my classification, I created a new layer from the ratio between the dry season and wet season images. The ratio layer was created by dividing the wet season image by the dry season image. I then combined the wet season image, the dry season image, and the ratio layer into one three-band data set for my classification of dry deciduous forests.

To delineate training sites and extract data for creating classification signatures, I obtained 50 seasonal pairs (dry season/wet season) of higher resolution imagery, specifically Landsat Enhanced Thematic Mapper Plus (ETM+) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery. Acquisition dates for this imagery ranged from 2000 to 2003. Dry season images were limited to March or April and wet season images to October, November and December. I compared these seasonal pairs and traced polygons of areas representative of dry deciduous forest, other forests, agriculture, and water. By visually overlaying the fine resolution leaf-on and leaf-off imagery I was able to better distinguish dry deciduous forest areas from other forest types (Figure 2.2). During the dry season, dry deciduous forests lose their leaves and do not show vegetation. This is in contrast to the evergreen forest and mixed forests, which show vegetative cover during the dry season. I created 307 polygons (average area of polygons was 18 km^2). Using the signature editor in ERDAS Imagine, I extracted mean and standard deviation for each polygon, based on all pixels within the polygon, for each of three bands of my input image.

For the final classification, I used a hybrid approach combining supervised and unsupervised classification techniques. Based on the 307 training sites, I ran a supervised classification with a maximum likelihood classifier. Though each polygon was identified as either dry forest, other forest, agriculture, or water, I did not compile the signatures into these major land cover categories prior to the classification. Instead I ran each as a its own class; i.e. produced several classes for each of the major land cover categories. I then refined the classification by assigning each of the 307 classes to one of my four major land cover categories. Means for dry forest training sites fall consistently within an area of overlap between forest and agriculture; these sites are spectrally very similar to either other forest training sites or agriculture training sites (Figure 2.3).

By using a large number of training sites and keeping them separate in the supervised classification, I was able to more finely distinguish the spectral characteristics of dry forests, making it easier to separate it from other land cover categories. This was particularly the case for bands one and two of my image, i.e. the wet and dry season MODIS data. Two-dimensional plots of the means for all training sites demonstrate: a) that all dry forest training sites are clustered (i.e. there is consistency in the spectral characteristics); and b) that all of them fall within the spectral transition from forest to agriculture. This plot also demonstrates the utility of maintaining 307 “sub”-categories rather than combining all of them into only four signatures for classification. The latter would have led to significant confusion of land cover categories. By reassigning classes into land cover categories after my supervised classification, I essentially performed an unsupervised classification as the second step, increasing my classification accuracy based on additional observations.

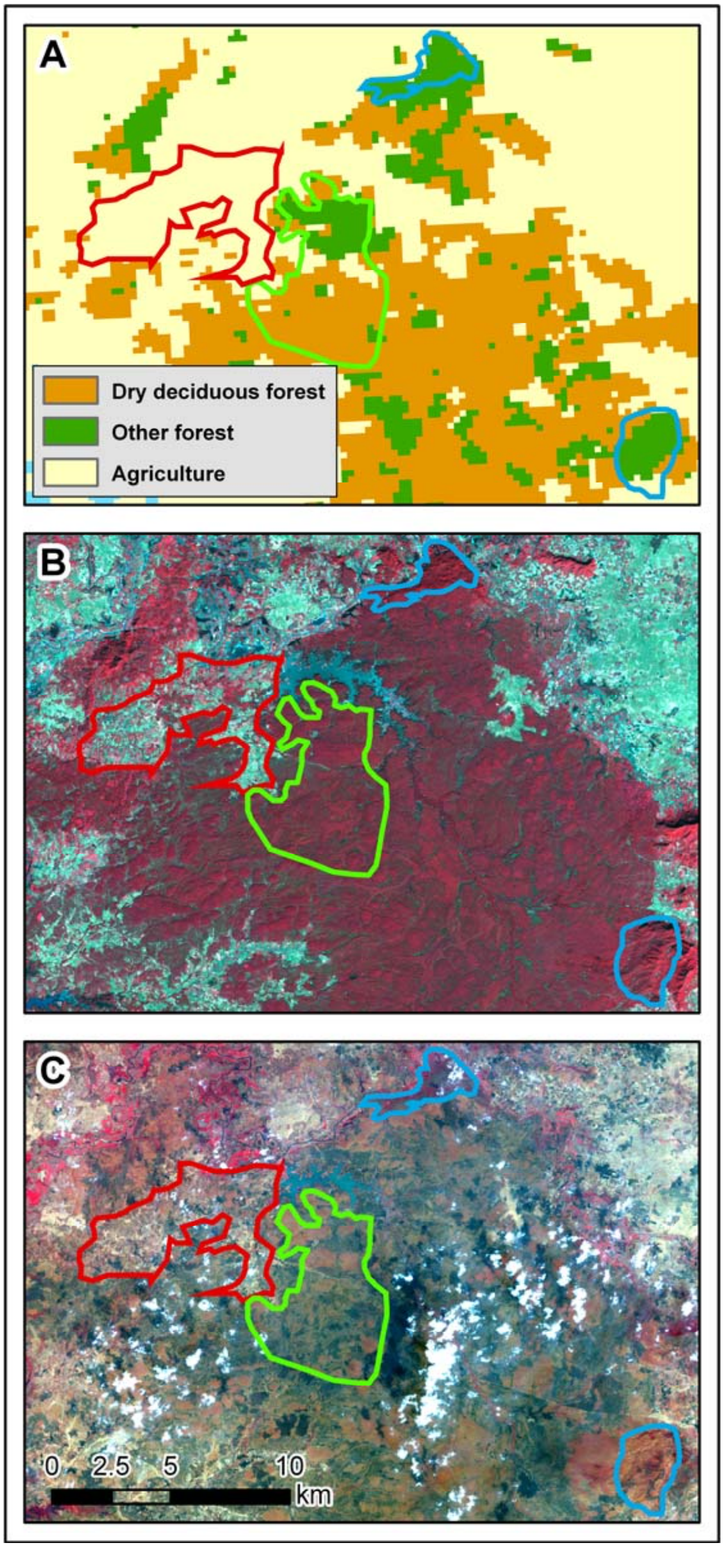

Figure 2.2. Examples of training polygons for extracting spectral statistics in supervised classification of MODIS NDVI data. A: Classified map; B: Leaf-on ASTER acquired January 2005; C. Leaf-off ASTER acquired March 2005. (Green polygons = dry forest; blue = other forest; red = agriculture).

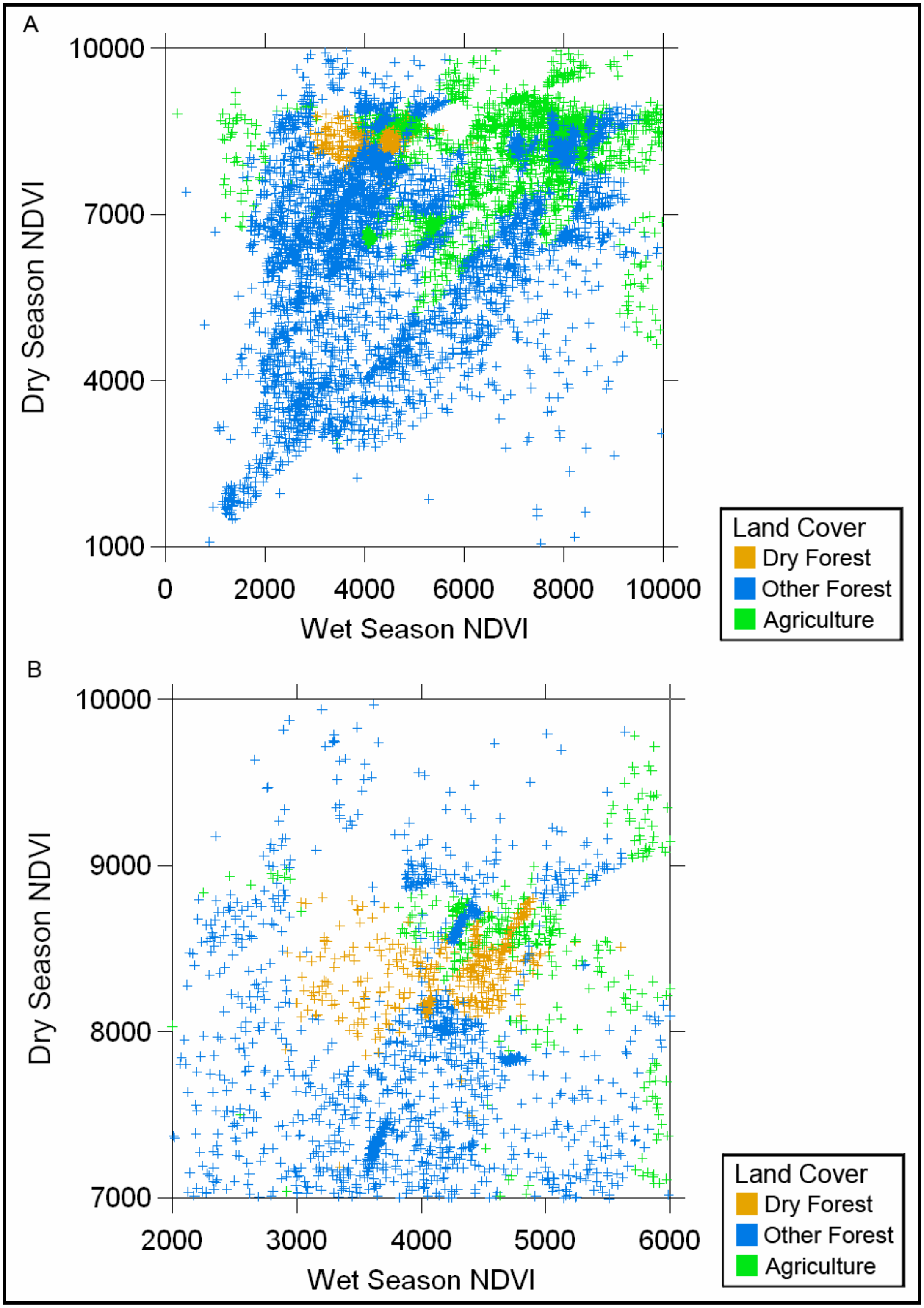

Figure 2.3. NDVI means for training sites in wet and dry seasons. A: All data; B: Subsection of data showing clusters of dry forest means. These charts demonstrate that by having many subcategories of dry forest, other forest, and agriculture I was able to separate these land cover types with very similar spectral properties.

Accuracy Assessment

To assess the accuracy of my dry deciduous forest map, I compared presence/absence of this ecosystem for 0.01 degree blocks on my map, with reference data based on finer resolution satellite imagery. This block-based approach allowed me to integrate validation data collected from imagery of varying spatial and spectral resolution (30 m resolution for Landsat ETM and 15 m for ASTER imagery) and provided an appropriate scale for evaluating my map. I used a Geographic Information System (GIS) to create a 0.01 decimal degree grid (approximately 10 km by 10 km) and tabulated the percentage for each land cover type in each grid cell. I randomly selected 500 grid cells to produce validation data. Of these, I used only the subset of 188 cells for which seasonal pairs of ASTER or Landsat ETM+ were available (Figure 2.4). For each selected grid cell I used the imagery to estimate the percent dry forest cover within the cell. Of the 188 cells assessed, 110 contained some dry forest, while 78 did not contain any dry forest. I assessed accuracy by running a Spearman's rank correlation comparing the percentage of dry forest cover in each of the classifications to that observed in the selected validation cells, and compared dry deciduous forest presence and absence in a confusion matrix.

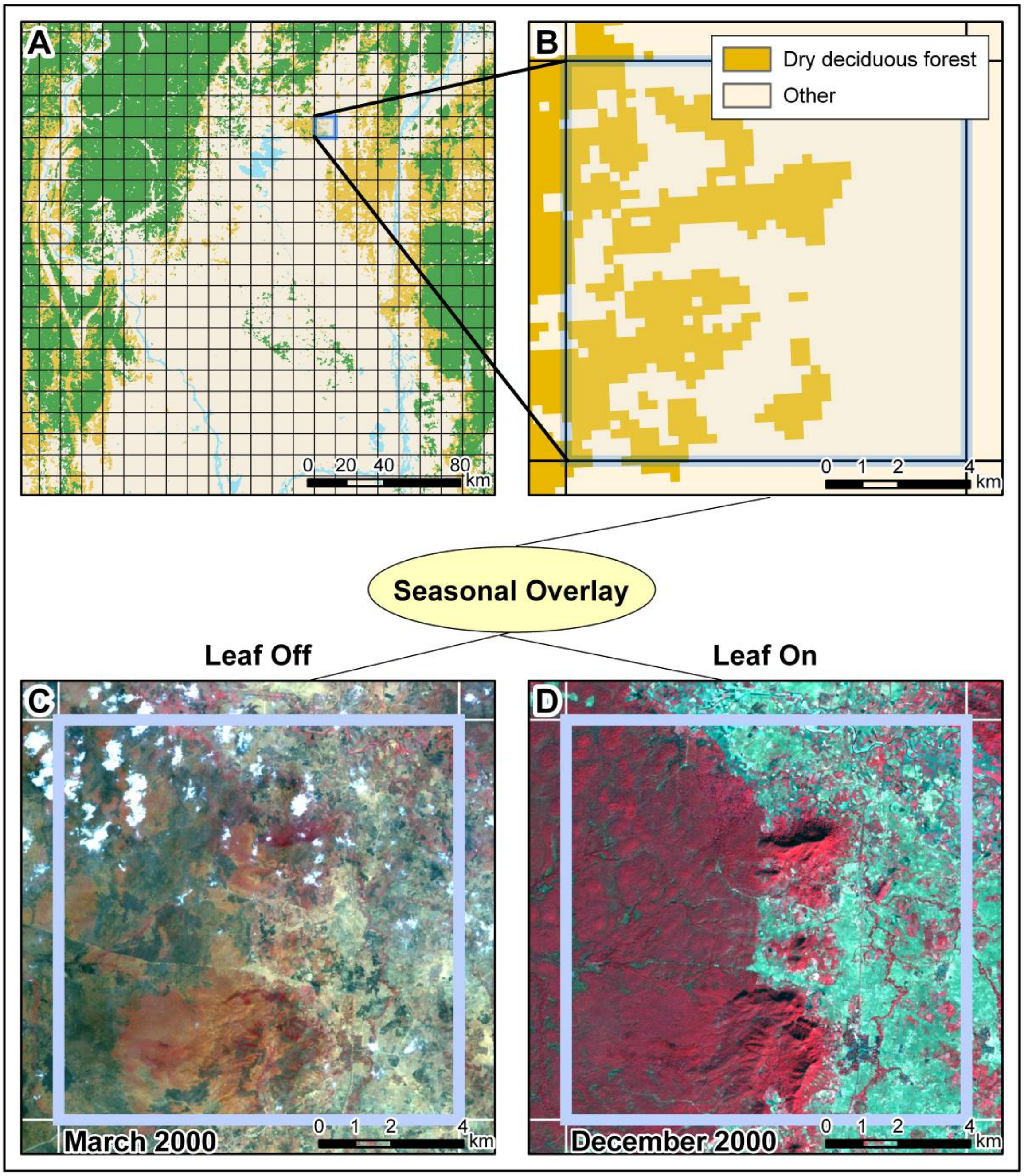

Figure 2.4. Selection of validation sites for accuracy assessment. A: Grid of 0.01 decimal cells from which cells were randomly selected for validation; B: Subset of a selected cell showing my map of dry deciduous forests; C: Subset grid showing leaf-off ASTER imagery; D: Subset of grid cell showing leaf-on ASTER imagery (color display: red = band 3N, green = band 2, blue = band 1).

Comparisons with Existing Regional Land Cover Maps

I also compared my dry deciduous forest map to other global and regional land cover maps, including the International Geosphere-Biosphere Programme (IGBP) DISCover, the MODIS/Terra Land Cover Classification (MLCC), and the Global Land Cover 2000 (GLC2000) (Table 2.1). The IGBP DISCover and MLCC are global data sets. In contrast, the GLC2000 is available in 18 regional products as well as being available as a global product. Regional products were produced by regional experts, so I assessed the South Asia regional product (Roy 2003) with the assumption that it would be more accurate for my area of interest than the global data set. I did not include the Miles et al. 2006 global assessment of dry forest because I was not able to obtain the data. I subset each of these maps to my study area and used my 188 validation cells points to determine accuracy of dry forest classes in each. To assess the level of spatial agreement among dry forest classifications of all maps, I conducted pairwise comparisons between maps and calculated area of overlap for dry forest categories.

Table 2.1. Existing regional and global land cover classifications used for comparisons with the dry deciduous forest map for Upper Myanmar.

Classification[1]	Source	Spatial resolution (km^2)	Imagery used [2]	Data acquisition	Dry forest classes	Overall accuracy assessed
MLCC	Boston University (http://edcimswww.cr.usgs.gov/pub/imswelcome/)	1	MODIS	Oct. 2000 – Oct. 2001	Open and closed shrubland, savannah, woody savannah	70.7 % (Strahler 2003)
GLC2000	European Commission's JRC (http:// www-gvm.jrc.it/glc2000/)	1	SPOT 4 VEGET-ATION	Nov. 1999 – Dec. 2000	Tropical dry deciduous forest, degraded forest, dry woodland, thorn forest, sparse woods, bush, savannah	ongoing
IGBP DISCover	USGS EROS DAAC (http://edc.usgs.gov/products/landcover/glcc.html)	1	AVHRR	April 1992 – March 1993	Open and closed shrubland, savannah, woody savannah	73.5% to 78.7% (Scepan 1999)

[1] MLCC = MODIS/Terra Land Cover Classification (Strahler et al. 1999; Friedl et al. 2002); GLC2000 = Global Land Cover 2000 (EMU 2003; Bartholome and Belward 2005; Roy 2003); IGBP DISCover = International Geosphere-Biosphere Programme (IGBP) DISCover (Belward et al. 1999; Loveland et al. 2000)
[2] MODIS = MODerate Resolution Imaging Spectroradiometer; SPOT = Satellite Pour l'Observation; AVHRR = Advanced Very High Resolution Radiometer.

Protection, Deforestation, and Fragmentation of Dry Deciduous Forests

To assess the degree to which existing dry deciduous forests are protected, I overlaid my final MODIS NDVI map with a protected areas layer for the study region and calculated percent protected. To determine potential impacts from deforestation, I compared my final data set with a recent deforestation assessment for Myanmar that was based on complete Landsat coverage of the country from the early 1990s and 2000s (Leimgruber et al. 2006). Finally, for assessing fragmentation of the remaining dry deciduous forests and for identifying the largest remaining patches, I calculated total area, mean patch size, and nearest neighbor distance for all existing patches, using FRAGSTATS (McGarigal et al. 2002)

RESULTS

Remaining Dry Deciduous Forest

Dry deciduous forests covered 24,163 km^2, constituting over 7% of the land cover within the study area (Figure 2.5, Table 2.2). Other forests stretched across more than half the study area (59%) resulting in 66% total forest cover. My dry deciduous forest map had an overall accuracy of 81%, and a classification accuracy of 77% for dry deciduous forest (Table 2.3, 2.4). All existing global or regional land cover data sets for the region had lower, and sometimes substantially lower, accuracies, compared to my map.

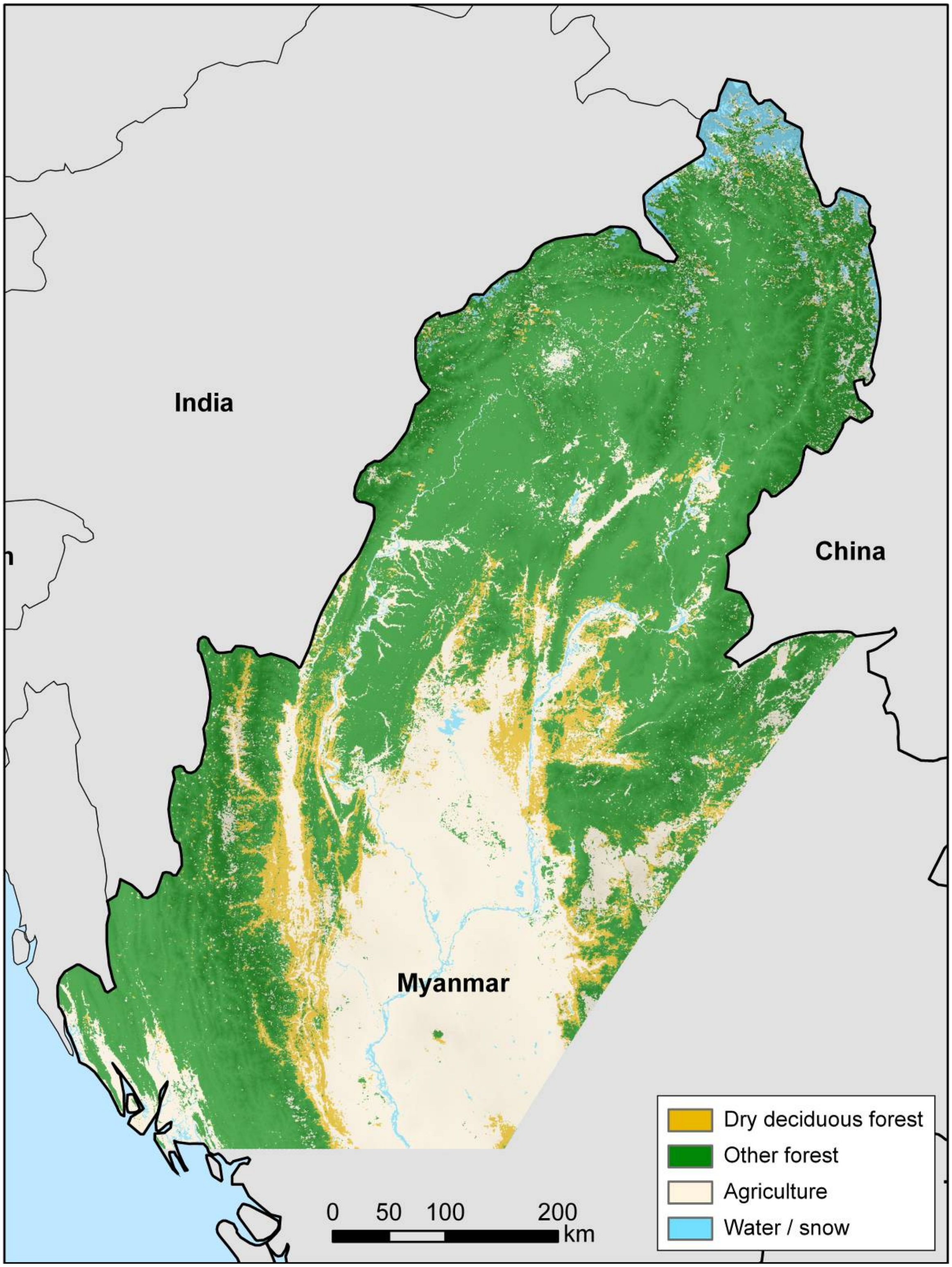

Figure 2.5. Dry deciduous forest in Upper Myanmar derived from seasonal MODIS NDVI imagery.

Table 2.2. Land cover calculated from a supervised classification of seasonal MODIS NDVI satellite imagery for Upper Myanmar.

Land cover type	Area (km^2)	Percent
Dry deciduous forest	24,163	7
Other forest	192,094	59
Agriculture	102,886	31
Water	8,251	3
Total	327,394	100

Table 2.3. Accuracy for the dry deciduous forest map (MODIS NDVI) and dry forest maps derived from regional and global land cover data sets.[1]

Data set	Dry forest area (km^2)	Percent accuracy				Correlation
		Percent dry forest	Dry forest	Other	Overall	
MODIS NDVI	24,163[2]	7.4	77[2]	87	81	0.787**
MLCC	33,647	10.2	78	66	73	0.522**
GLC 2000	20,132	6.1	61	91	73	0.298*
IGBP DISCover	18,954	5.8	44	74	56	0.244*

[1] MODIS NDVI = dry forest map produced by this study using seasonal MODIS NDVI imagery in a supervised classification approach; MLCC = MODIS/Terra Land Cover Classification; GLC2000 = Global Land Cover 2000; IGBP DISCover = International Geosphere-Biosphere Programme (IGBP) DISCover.
[2] My MODIS NDVI map focused on a specific subset of dry forest.
** $p = 0.001$
* $p = 0.01$

Inspection of omission and commission errors for dry forest and dry deciduous forests produced a similar pattern (Table 2.4). My map generally had lower omission and commission errors than all other maps, with the exception of the MLCC which had a slightly lower omission error but a larger commission error. Most data sets had greater omission than commission errors, indicating that these maps are more likely to miss dry and dry deciduous forests than to over-predict them. MLCC performed almost as well as my map, but the GLCC and especially the IGBP performed poorly in delineating existing dry forest habitats. IGBP DISCover's poor accuracy may be related to the discrepancy between data acquisition dates of imagery used for their classification (1992-1993) and that used for my validation data (2000-2003). Comparing the percent dry forest cover estimates within validation cells to each of the other maps I found significant correlations for each; however my map had the highest correlation values (Table 2.3).

Table 2.4. Omission and commission errors.

Date set[1]	Dry forest	
	Omission	Commission
MODIS NDVI[2]	23	10
MLCC	22	23
GLC 2000	39	10
IGBP DISCover	56	29

[1] MODIS NDVI = dry forest map produced by this study using seasonal MODIS NDVI imagery in a supervised classification approach; MLCC = MODIS/Terra Land Cover Classification; GLC2000 = Global Land Cover 2000; IGBP DISCover = International Geosphere-Biosphere Programme (IGBP) DISCover.
[2] My MODIS NDVI map focused on a specific subset of dry forest.

Spatial agreement for dry forest areas when compared across all maps was extremely low (Table 2.5). Less than 1% of the study area was classified as dry forest by all 4 maps and only 7% overlaps in 3 out of the 4 maps (Figure 2.6). My map shared less than one-eighth of its predicted dry forest area with one of the other maps (Figure 2.7). The best spatial agreement exists between MLCC and GLC2000, but even these datasets had only 20% overlap.

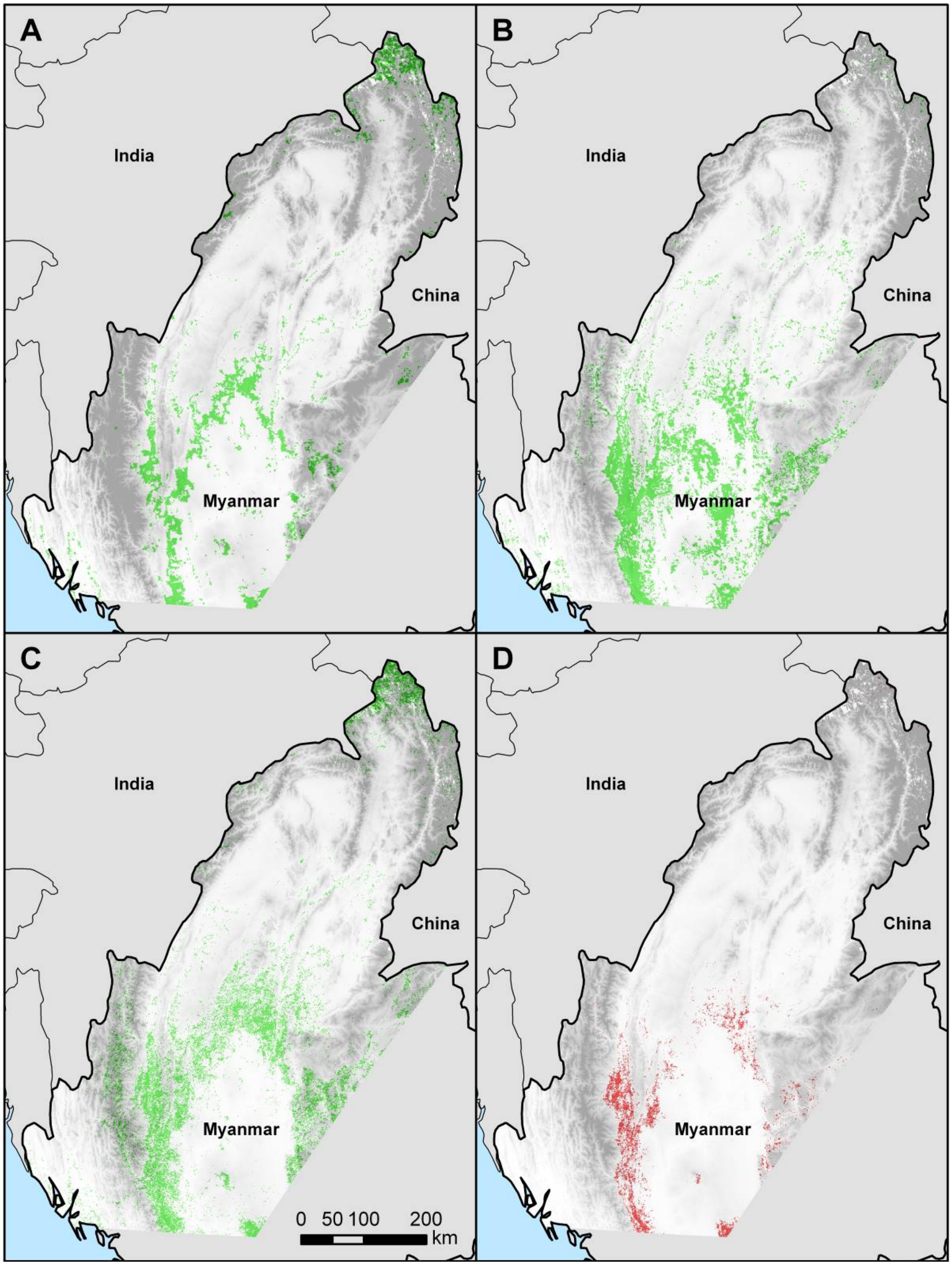

Figure 2.6. Comparison of dry forest data from regional and global forest maps to assess overlap and spatial agreement. A: IGBP DISCover; B: Global Land Cover 2000; C: MODIS/Terra Land Cover Classification; D: Areas that are classified as dry forest in at least three out of four dry forest maps (GLCC, GLC2000, MLCC and MODIS NDVI).

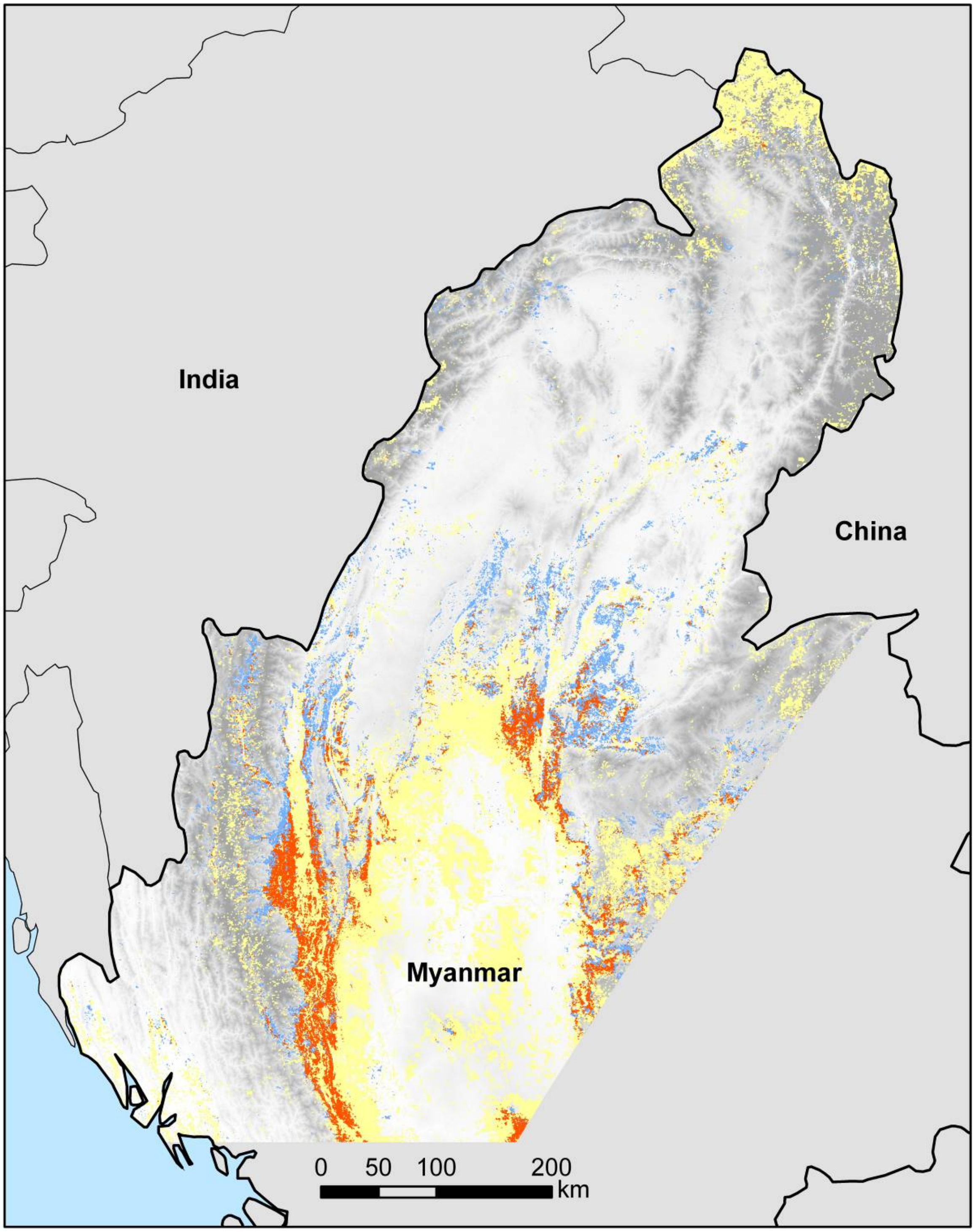

Figure 2.7. Comparison of MODIS NDVI map for dry deciduous forest with three other dry forest classifications. Red=areas classified dry deciduous forest in the MODIS NDVI map and at least one other map; blue=areas classified as dry deciduous forest only in MODIS NDVI map; yellow=areas classified as dry forest by other maps.

Table 2.5. Spatial agreement for dry forest between the MODIS NDVI map and maps derived from regional and global land cover data sets.[1]

	MODIS NDVI		MLCC		GLC 2000	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
MLCC[2]	7,311	14				
GLC2000	7,545	14	11,202	20		
IGBP DISCover	1,842	4	7,205	17	6,730	14

[1] MODIS NDVI = dry forest map produced by this study using seasonal MODIS NDVI imagery in a supervised classification approach; MLCC = MODIS/Terra Land Cover Classification; GLC2000 = Global Land Cover 2000; IGBP DISCover = International Geosphere-Biosphere Programme (IGBP) DISCover.
[2] My MODIS NDVI map focused on a specific subset of dry forest.

Protection and Fragmentation

Based on my map, I found that dry deciduous forest is the least protected forest type in Myanmar with only 4% (1,065 km^2) located inside protected areas, while 8% (14,662 km^2) of other forest areas are protected. Only 7% of area designated with protected status are classified as dry deciduous forest; the remaining 93% of protected lands consist of some other ecosystem. Extant dry deciduous forest is highly fragmented, with over 11,000 patches less than 1 km^2 and 1,797 patches greater than 1 km^2. The mean patch size for patches greater than 1 km^2 is 12.7 km^2 (median 2.19 km^2) and the mean nearest neighbor distance is 1.8 km. Only 27 patches cover an area of 100 km^2 or greater (Figure 2.8); 7 of these patches demonstrate some dry deciduous forest protection, however, 3 of these have less than 1% of their dry deciduous forest area within a protected area boundary.

Most of these larger patches had less than 1% deforestation from 1990 to 2000; however 8 patches had deforestation levels ranging from 1 to 8%. Only one patch is completely protected, that found in Chatthin Wildlife Sanctuary, a 362 km^2 protected area comprised primarily of dry deciduous forest (Chapter 4). Four percent (978 km^2) of the dry deciduous forest area from my map was classified as deforestation in the 1990-2000 countrywide assessment.

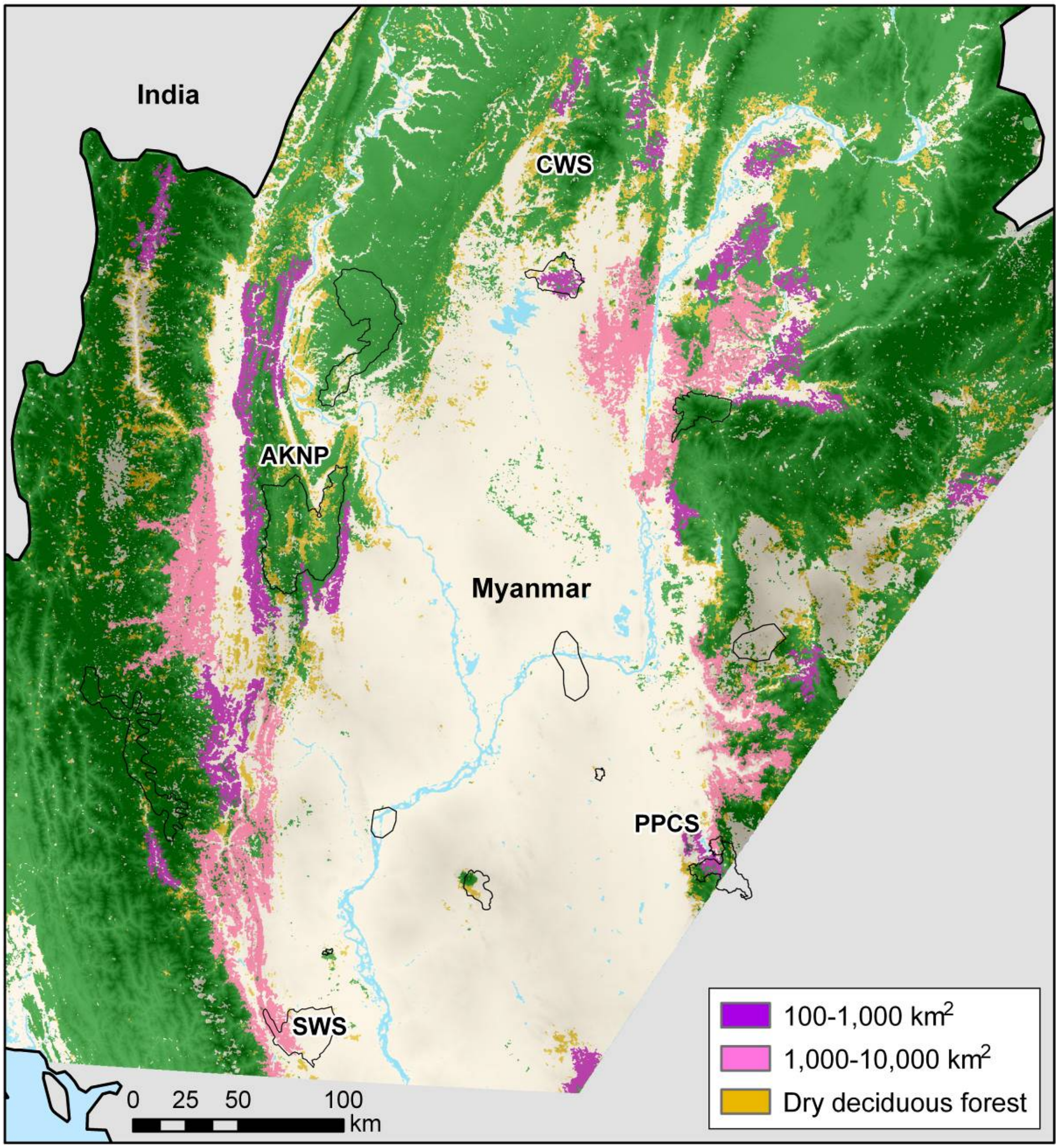

Figure 2.8. Remaining large (>100 km^2) tracts of dry deciduous forests and protected areas in Upper Myanmar. Protected areas are outlined in black; CWS=Chatthin Wildlife Sanctuary; AKNP=Alaungdaw Kathapa National Park; PPCS= Panlaung-Pyadalin Cave Sanctuary; SWS=Shwesettaw Wildlife Sanctuary.

DISCUSSION

Status of Dry Deciduous Forest in Upper Myanmar

My map demonstrates that only 24,000 km^2 of dry deciduous forest remains in Upper Myanmar. This is consistent with a recent deforestation study for Myanmar that reported the second highest deforestation rates for the country were in the northern edge of the central dry zone (Leimgruber et al. 2006)—the part of the country where dry deciduous forests are dominant.

Almost all of Myanmar's remaining dry deciduous forest is located in a horseshoe-shaped zone, wedged between the country's hill region and its central dry zone. The dry zone probably once had substantial dry deciduous forest cover (Kurz 1877; Stamp 1925), but this rapidly disappeared as human populations and agriculture expanded. Now, the remaining forests are restricted to the fringes of their environmental envelope (Koy et al. 2005; Leimgruber et al. 2006). Usually they are not found at elevations above 1,200 m, giving way to hill and pine forest as elevation increases (Stamp 1925). As the country's population continues to grow, I expect these fringe areas gradually to be converted to agriculture.

Detailed comparisons of my dry deciduous forest map with the 1990-2000 country wide deforestation map produced by Leimgruber et al. (2006) reveal that 4% of the dry deciduous forests in my map were already being affected by deforestation and forest degradation during this time. Though these areas had not yet been converted to agriculture they had lost much of their canopy, probably to fuelwood collection, charcoal production, and similar degradations (Leimgruber et al. 2006).

Only 4% of Myanmar's remaining dry deciduous forest is included in existing protected areas (Figure 2.8). The latter include Panlaung-Pyadalin Cave Wildlife Sanctuary, Shwesettaw Wildlife Sanctuary, Alaungdaw Kathapa National Park, and Chatthin Wildlife Sanctuary, which overlap with one of the patches >100 km^2 . Most of these protected areas contain only small proportions of dry forest, with the exception of Chatthin Wildlife Sanctuary, which is primarily composed of intact dry deciduous forest. Data from a case study using Landsat and ASTER satellite imagery to assess spatial and temporal deforestation dynamics demonstrates how legal protection can slow deforestation and degradation of dry deciduous forests (Chapter 3). The same study also finds high rates of decline for the forests outside Chatthin; most of this study area's natural cover probably is dry deciduous forest.

In the past these areas provided critical habitat for many rare or endangered species such as tiger (*Panthera tigris*), elephant (*Elephas maximus*), banteng (*Bos javanicus*), gaur (*Bos gaurus*), dhole (*Cuon alpinus*), Eld's deer (*Cervus eldi*), and the Burmese star tortoise (*Geochelone platynota*) (Tordoff et al. 2005). Dry deciduous forests of Myanmar are under enormous pressure from human use demands (Rao et al. 2002; Chapter 4). Even the protected areas that encompass dry deciduous forest show evidence of hunting, fuelwood collection, and non timber forest product extraction by local people (Rao et al. 2002; Lynam 2003). Most also support human settlements, cultivation, and grazing. Some even have military encampments inside their boundaries (i.e. Shwesettaw Wildlife Sanctuary and Alaungdaw Kathapa National Park), and some experience commercial timber extraction (i.e. Shwesettaw Wildlife Sanctuary and Panlaung-Pyadalin Cave Wildlife Sanctuary) (Rao et al. 2002; Lynam 2003).

Mapping Dry Deciduous Forests from Existing Land Cover Data

Regional and global land cover data did not perform as well at predicting presence of dry forests in Upper Myanmar, as compared with the regional scale map derived from seasonal MODIS data. Most data show little thematic or spatial overlap, indicating that there is little consistency in how these forests are mapped. Even in classification schemes that employ the IGBP land cover classes as a standard, i.e. the MLCC and the IGBP DISCover, overlap was surprisingly low. There are several possible explanations for the lower accuracy and low agreement in regional and global land cover data as compared to my own map produced from seasonal MODIS NDVI. These explanations include differences in: a) dry and dry deciduous forest definitions; b) canopy densities mapped; c) characteristics of the satellite imagery used; d) availability of ground reference; e) classification techniques; and f) scale and resolution.

Dry Deciduous Forest Definitions

Forest definitions used for land cover mapping vary significantly among the countries and interest groups delineating these resources (Lund 1999; Matthews 2001). Sometimes definition differences can lead to vastly different mapping outcomes and results (Matthews 2001). For example, the 1990 global Forest Resources Assessment (FAO 1995) defined forests as areas with ≥20% canopy cover but, for their 2000 assessment, revised this definition to ≥10% canopy cover. As a result, the amount of forest cover thus assessed for Australia increased 40%, from 40 million ha in 1990 up to 158 million ha in 2000 (Matthews 2001). Definition discrepancies may partly explain the limited overlap between dry and dry deciduous forest maps assessed in my study. None of the data I utilized explicitly distinguishes dry deciduous forest as a category but rather they include several dry land categories that might encompass this forest type (Table 2.1; Friedl et al. 2002; Giri et al. 2005; Miles et al. 2006). I summarized these categories into a dry forest class, but, in other instances, comparisons could be seriously compromised if such categories are based on vastly different definitions.

Dry land or dry forest categories make up a small percentage of all land cover in regional and global data, i.e. 10% of the MLCC, 11% of the GLC2000, and 6% of the GLCC. Thus, their accuracy has less effect on the overall accuracy of the entire data set than the accuracy of land cover types covering large areas. Most analysts will try to maximize classification accuracy for dominant land cover classes. My map only differentiates between dry deciduous forests and other ecosystems. This allowed me to maximize classification accuracy for this single land cover class and allowed for a better separation than would otherwise have been possible.

Reducing the area to be classified as I did can help to achieve greater classification accuracies (Foody 2005). My study area represents only a small portion of the area covered by the regional and global data sets used in my study (327,394 km^2 in my study as compared to global coverage or 16,749,893 km^2 for the GLC2000). In contrast to this focus on a smaller area, classifying land cover over larger areas requires dealing with greater variability in seasonal and phenological patterns for a respective ecosystem. For example, leaf-off in Myanmar's dry forests occurs at a different time then leaf-off in Sri Lanka's dry zone. Similarly, the larger the area included in the classification, the greater the number of ecosystems and land cover types that need to be separated. As the number of ecosystems increases, so does the likelihood that some of these ecosystems are similar in spectral reflectance patterns, although they may be very different in ecosystem function and pattern. These problems greatly increase the risk of misclassifying different land cover types.

Canopy Densities and Classification Techniques

Dry deciduous forests are often characterized by low canopy densities and the interspersion of forest trees with grassy meadows or understories (Ruangpanit 1995; Koy et al. 2005). This high degree of spatial heterogeneity exacerbates the mixed pixel problem and potential error (Steele et al. 1998). The mixed pixel problem is also likely to increase with decreases in spatial resolution of the satellite data used for mapping (Haertel & Shimabukuro 2005). In addition, dry deciduous forests can easily be confused with scrublands and degraded forests since they often have similarly reduced canopy cover and a high degree of spatial heterogeneity (Grainger 1999).

Seasonal MODIS NDVI data were useful for the delineation of dry deciduous forests in Upper Myanmar. My map improved classification accuracies when compared to existing data sets. Using seasonal data with image data collected during leaf-on and leaf-off periods allowed me to reduce classification errors stemming from the confusion of scrubland and dry deciduous forest. Myanmar's dry deciduous forests have a distinct seasonal phenology with leaf-on at the end of the rainy season and leaf-off at the end of the dry season. Other open habitats such as scrublands and agriculture have less distinct phenologies.

Recognizing that transitions between different forested ecosystems are gradual and not abrupt, DeFries et al. (1999 and 2000) developed a regression algorithm that predicted tree density on the basis of spectral reflectance from MODIS data. Though this approach provides a means for comparing different forest classifications on the basis of tree densities, it suffers from saturation for radiance measured over areas with very low or very high densities of trees (White et al. 2005). Thus, this remote sensing technique may not be applicable for separating other ecosystems from dry forests with very low tree densities.

A recent map published by the World Conservation Monitoring Centre (Miles et al. 2006) provides a global dry forest estimate based on the vegetation continuous field technique developed by DeFries et al. (1999 and 2000) and known biogeographic realms (Olson et al. 2001). This map omits all dry deciduous forest present in my validation sites and the total dry forest for Myanmar is represented by fewer than ten 100-200 km^2 patches. Probably the difference is due to the broader scale (global) and lower resolution (10 km^2) of the analysis, and the fact that Myanmar's dry deciduous forests have very low canopy coverage. Koy et al. (2005) found the average for canopy cover for dry forests in northern Myanmar was 34.2% ± 2.46%, while Miles et al. (2006) considered in their analysis only areas with 40% or greater canopy cover. This is another example of how varying forest definitions can make a dramatic difference in results.

Satellite Imagery and Ground Truthing

Spatial resolution is substantially higher in my map, compared to the data sets that were created based on AVHRR and SPOT 4 VEGTATION imagery produced at 1 km^2. Even the MLCC, though initially based on 250 and 500 m resolution MODIS data, was resampled to 1 km and has a lower resolution in the final product (Giri et al. 2005).

MODIS and MODIS NDVI are improved data products for the delineation of vegetation types when compared to AVHRR (Huete et al. 2002; Fensholt & Sandholt 2005). These differences can play a substantial role when trying to identify and delineate a specific ecosystem type such as tropical dry forest.

Ground data referencing different forest ecosystems are essential during the training stage of a land cover classification. Acquiring reference data for large areas such as those needed for regional and global classifications can be difficult and expensive (Wickham et al. 2004; Baraldi 2005). Mid- and high-resolution data can substitute for ground data, especially when trying to produce a land cover classification from coarser resolution data such as MODIS or AVHRR. Researchers at the Smithsonian's Conservation and Research Center, including myself, have many years of experience working on the ground in Myanmar's dry forests. From these studies, we have compiled large databases, including several land cover classifications on forest ecosystems (McShea et al. 1999; Koy et al. 2005; Leimgruber et al. 2006), and extensive knowledge about the phenology, characteristics and distribution of dry deciduous forests and other ecosystems throughout the country. This combined knowledge was extremely useful to me when identifying training sites for the classification, and when assessing the forest types on the Landsat and ASTER imagery used in the accuracy assessment.

IMPLICATIONS FOR CONSERVATION

Remaining Dry Forests of Upper Myanmar

The remaining dry deciduous forests of Upper Myanmar are in a similar condition to dry forests around the world: highly threatened and not well protected. Of the 24,000 km^2 remaining I found that only 4% is under some kind of protection. The remaining patches are highly fragmented; only 27 patches greater than 100 km^2 exist in my study area. There is an urgent need to expand protection of the few tropical dry forest patches that remain in Myanmar. While the country currently has one of the highest percentages of forest cover in mainland Southeast Asia, its tropical dry forests have been experiencing greater loss than other forest types in Myanmar due to human activities, and are less well protected than these other forest types. The few existing protected areas are under intense pressures and will likely decline without substantive improvements. However, there are also several large and medium size patches that potentially could be added to the country's protected area system, including 5 that are greater than 1,000 km^2. Even the smaller patches can be important strongholds for endangered species. For example, Chatthin Wildlife Sanctuary, which is only 362 km^2, supports the largest remaining population of the endangered Eld's deer. These remaining patches are key strongholds for species as well as a valued resource for people living near them. To preserve these remnants it is important to find a balance between human needs and the health of the forests.

Remote Sensing and Conservation

Through advancements in remote sensing and computer technology we are now able to monitor and map the globe in ways that were not possible just 20 years ago (Leimgruber et al. 2005). It has become easy to use these free, readily available global data sets for any number of objectives. However, it is important to consider how these data sets were created, their purposes, and their specifications before employing them in research. Producing data sets at a global scale presents many challenges in dealing with variation in phenology and habitat types across regional scales. Working at 1 km resolution makes it more difficult to distinguish subtle habitat changes and very rarely can analysts have detailed on the ground experience around the globe. When selecting an existing land cover classification for research purposes it is important to consider the methodology and assumptions that have gone into the classification within the context of the specific research questions and objectives.

I have presented a relatively simple technique that may be used to develop a more reliable dry deciduous forest map than those otherwise available, based on imagery and NDVI products that are available for free on the Internet. The MODIS NDVI product tiles cover a 1,200 km by 1,200 km area; a huge geographical area can be obtained with no need for geo-referencing or making mosaics of countless images. The 250 m resolution provides better detail than existing land cover maps and allows for more precise classifications. Using higher resolution reference data to collect training sites facilitates recognition of representative dry forest areas. My map estimated total forest cover at 66% across the study area—very similar to the 67% forest cover estimated in the forest/nonforest classification which was based on complete Landsat coverage of the country (Leimgruber et al. 2006). This technique benefits from some of the advantages of higher resolution imagery, but improves efficiency through the use of MODIS NDVI products as the basis for the classification.

Chapter 3: Spatial and Temporal Deforestation Dynamics in Protected and Unprotected Dry Forests: A Case Study from Myanmar (Burma)

ABSTRACT

I analyzed the spatial and temporal changes in land cover from 1972 through 2005 in and around Chatthin Wildlife Sanctuary (CWS), a tropical dry forest protected area in Myanmar (Burma). To determine the spatial and temporal deforestation dynamics in the area I analyzed five satellite images covering 32 years (Landsat MSS: 1973; Landsat TM: 1989, 1992; Landsat ETM+: 2001; ASTER: 2005). CWS is one of the largest remaining protected patches of tropical dry forest in Southeast Asia and supports over half the remaining wild population of the endangered Eld's deer. Both the dry forest and these deer are becoming increasingly rare throughout Asia. Between 1973 and 2005, 62% of forest cover was lost at an annual rate of 1.93%. Though still considerable, deforestation rates inside the sanctuary were dramatically lower than this, with only 16% of the 1973 forest cover lost by 2005 (0.49% annually). My analysis of temporal patterns of deforestation indicates that the highest rate of forest loss occurred during the 1990s; however, flooding in 2000-2001 from a hydroelectric dam caused major changes in land cover and land use. Conversion to agriculture, shifting agriculture, and flooding due to the dam were the main drivers of deforestation in the area. Though the forest area of CWS is gradually declining from the boundary inwards, there is evidence that protection of the sanctuary has been effective in slowing the decline. However, without changes to

government land use policies in surrounding areas, the forests of CWS will continue to decline. Establishing new protected areas for remaining dry forests and finding ways to mitigate human impacts on existing forests are both needed to protect the remaining dry forests and the species they support.

INTRODUCTION

Deforestation is a major threat to global biodiversity (Wilson 1992; Sala et al. 2000; Novacek & Cleland 2001; Brooks et al. 2002; Brook et al. 2003). Deforestation directly eliminates many plant species and their associated fauna, opens up previously pristine and remote areas for exploitation and poaching of wildlife and plants, and frequently concludes with the permanent conversion of forested lands into other land uses, such as agriculture (Ehrlich 1988; Skole & Tucker 1993; Houghton 1994; Heywood 1995). Most deforestation research focuses on tropical rainforests, because of their well-publicized species richness (Myers 1984; Gentry 1984; Sutton et al. 1984; Raven 1988). However, tropical dry forests have been reported to be more threatened, less protected and especially susceptible to deforestation from land use conversion, in comparison to tropical rain forests (Bunyavejchewin 1982; Murphy & Lugo 1986; Janzen 1988; Bullock et al. 1995; Maass 1995). In Myanmar (Burma), for example, tropical dry forests experienced some of the highest deforestation rates of any forest types during the 1990s (Leimgruber et al. 2006), yet only 4% of these forests are legally protected as opposed to 8% of other forest types (Chapter 2).

Protection of tropical dry forests poses problems less frequently encountered with tropical rain forest protection, because the dry forests are more often associated with high human population densities (Murphy & Lugo 1986) and are more susceptible to extraction pressures than are the rain forests (Bullock et al. 1995; Maass 1995; Miles et al. 2006). Dry forests are usually places that have been exposed for centuries to extended human habitation and land use (Janzen 1988; Stott 1990). Tropical dry forests are frequently associated with arable soils that are preferred for agricultural use, particularly for rice and sugar cane. Because of these attributes, rural populations in the Myanmar's central dry zone make up about 80% of the country's population and continue to increase.

Myanmar has more remaining forest cover than most countries on the Southeast Asian mainland (Leimgruber et al. 2006) and also possesses some of the last strongholds for tropical dry forests in Southeast Asia. While much of its tropical dry forest has already been lost, some substantial patches are left. Chatthin Wildlife Sanctuary (CWS) is one of the best examples of protected dry forest patches in the country, and in Southeast Asia as a whole. It also supports the only population of the endangered Eld's deer (*Cervus eldi*) that is likely to be viable for the long-term (McShea, personal communication). Little is known about the status of the forests in and around Chatthin, or about their rate of decline. We also possess no quantitative assessment of how effective this protected area is in preserving its associated dry forests.

The effectiveness of protected area management for safeguarding biodiversity is disputed (Bruner et al. 2001; Liu et al. 2001; Rao et al. 2002; Myint Aung 2006). Much of the existing research relies on a combination of interview survey data, information on staffing and financing from responsible government agencies, and expert assessments (Rao et al. 2002; Ervin 2003; Goodman 2003; Myint Aung et al. 2004; Struhsaker et al. 2005; Myint Aung 2006). Satellite remote sensing provides an additional tool for such assessments, delivering accurate and current information about land cover changes in even the most remote protected areas (Zheng et al. 1997; Foody & Cutler 2003; Linkie & Smith 2004; Trigg 2006). However, frequently these analyses rely on only a few satellite images, collected at one or two dates in the recent past. These assessments likely are failing to capture inter-annual changes in land cover. I used five satellite images of CWS and surrounding areas—spanning 32 years—to study the spatial and temporal deforestation dynamics of the dry forests of this region. I used these data to address five research questions:

1) How much forest is left within CWS and surrounding areas?
2) How much forest has been lost and at what rate?
3) What are the spatial and temporal dynamics and patterns of deforestation?
4) How effective is CWS at protecting forests and preventing deforestation?
5) What are the driving forces of land cover change in the area, and specifically inside CWS?

METHODS

Study Area

CWS is located at the northern edge of the central dry zone (95^o 24'E—9 95^o 40'E, 23^o 30'N—23^o 42'N), an area historically dominated by forest (Kurz 1877; Stamp 1925) but now primarily used for agriculture (Leimgruber et al. 2006; Chapter 2). The monsoonal climate has three seasons, including a rainy season (~0.4 m rainfall annually), a cool-dry season, and a hot-dry season (Myint Aung et al. 2004). Crops are grown August through January. During the hot-dry season (February through May) the area burns, owing to fires deriving from both human and natural causes. The dry deciduous forest, known locally as "Indaing" are dominated by the dipterocarp species *Dipterocarpus tuberculatus*; grassland and evergreen forest patches are intermittently found throughout.

To create a boundary layer for use in a Geographic Information System (GIS), the staff of CWS recorded Global Positioning System (GPS) positions along CWS boundary pillars. Using these GPS locations and drawing also on the knowledge of the park warden, I digitized the complete park boundary. Between pillar locations we followed natural features such as topographic contours and streams. The ground survey demonstrated that the actual area of CWS was 362 km^2, including a 53 km^2 buffer zone (Figure 3.1).

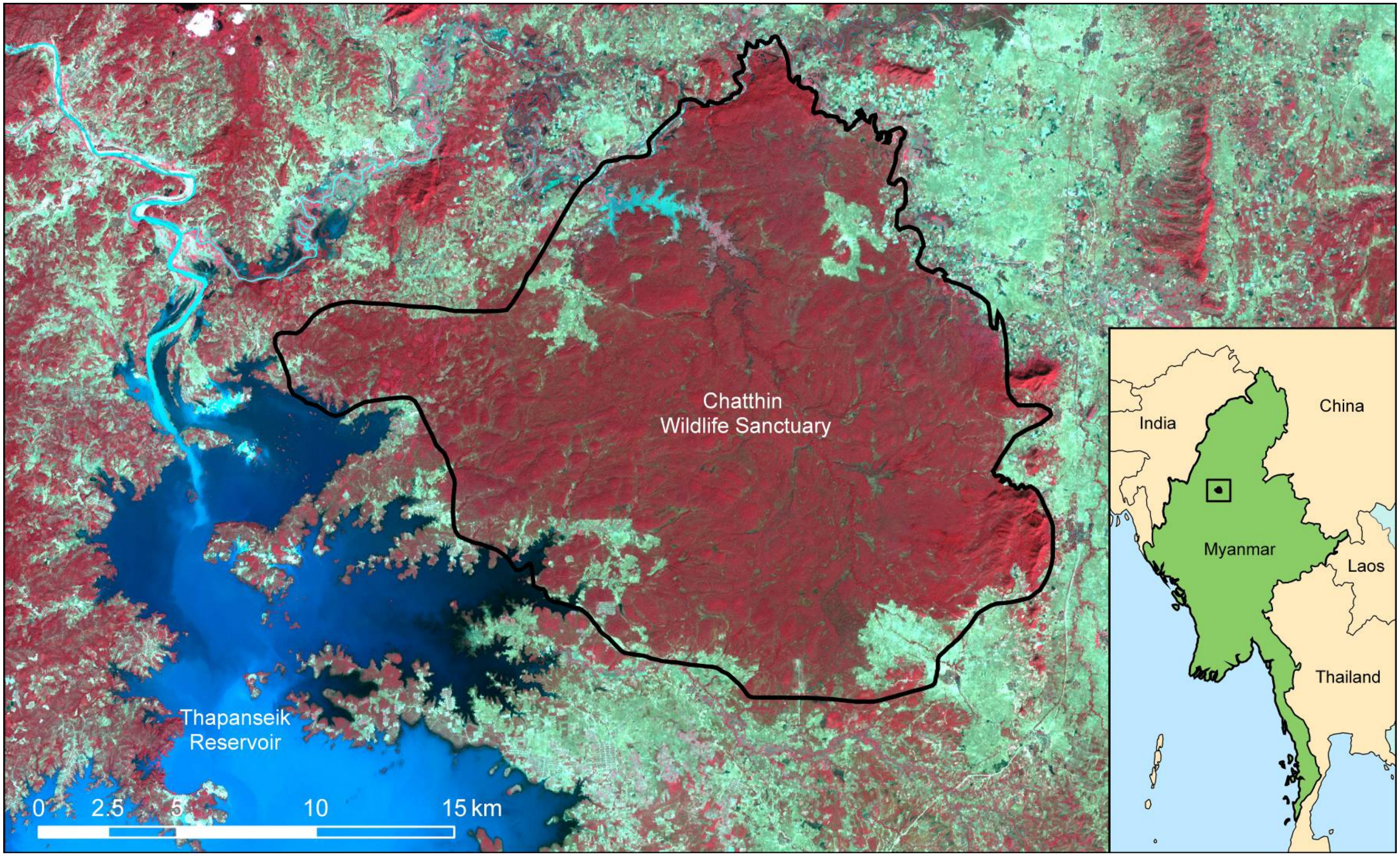

Figure 3.1. Chatthin Wildlife Sanctuary and Thapanseik Reservoir. ASTER image acquired January 2005 (color display: red = band 3N, green = band 2, blue = band 1).

CWS is one of Myanmar's oldest protected areas, with a complex environmental history (Myint Aung et al. 2004). Under British rule the area was gazetted as a fuel reserve in 1919. Then in 1941 its status was changed to sanctuary, to help conserve the Eld's deer (Myint Aung et al. 2004). Three villages inside the sanctuary have been "grandfathered" into the reserve. There are also 31 villages within 10 km of the sanctuary, totaling approximately 4,000 households and over 25,000 people. A legally sanctioned buffer zone was established in the 1990s.

Villagers in the area are primarily subsistence farmers who depend on the sanctuary's forest to supplement their harvest (Chapter 4). For a more detailed description of CWS history, see Myint Aung et al. (2004), and for information on socioeconomics and their influence on CWS consult Allendorf et al. (submitted) and Chapter 4.

Satellite Data

To obtain satellite imagery for my analysis of temporal and spatial deforestation dynamics I browsed imagery archives for Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery. I selected the five best satellite images spanning 32 years, 1973-2005 (Table 3.1). I had difficulty getting images at regularly occurring intervals because I took only images with minimal cloud cover, and because much of the other Landsat data is not available. All of these images were recorded at the end of the rainy season, or during the early dry season when leaves have not yet begun to fall. Imagery from this time period is ideal for classifying tropical dry forests because generally it has the lowest cloud cover and highest leaf cover of any time during the year. Cloud cover in the imagery I chose amounted to less than 1%, and I removed all clouds and areas covered by cloud shadow from further analysis. To assure good co-registration of all images, I georeferenced each of the images to an orthorectified Landsat image from 1989 using ground control points that were identifiable in the 1989 and the image being registered. I obtained the orthorectified Landsat image from NASA's Geocover (Tucker et al. 2004). My deforestation analysis was restricted to the 3,897 km^2 area covered by the ASTER image, which includes CWS, Thapanseik Dam and the immediate surroundings (Figure 3.2).

Table 3.1. Satellite imagery specifications and dates of acquisition.

Acquisition date	Sensor	Spatial Resolution	Bands Used
19 November 1973	Landsat Multispectral Scanner (MSS)	57 m	1,2,3,4
23 January 1989	Landsat Thematic Mapper (TM)	30 m	1,2,3,4,5,7
25 December 1992	Landsat TM	30 m	1,2,3,4,5,7
23 October 2001	Landsat Enhanced TM Plus (ETM+)	30 m	1,2,3,4,5,7
3 January 2005	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	15 m	1,2,3N

Measuring Deforestation

I performed unsupervised classifications on each image separately, using clustering (ISODATA algorithm; ERDAS 1997), cluster labeling, and cluster busting (Jensen et al. 1987; Rutchey & Vilcheck 1994) as needed. Clusters were interpreted as forest (>30%

canopy cover), non-forest, or water and then recoded. To assess classification accuracy of these maps, I used 245 ground-truthing points collected in the area during 2001 and compared them to the 2001 classification. Staff of CWS conducted vegetation surveys at the points, using a GPS unit to obtain locations. Survey points were selected randomly within a homogeneous area that was not near an edge of the vegetation type. Vegetation plots covered a 22 m diameter area; I assumed the type of vegetation found at the point was representative of the entire pixel with which it overlapped. Based on these vegetation surveys I designated each point as forest or non-forest and cross-tabulated these designations with the categories in the 2001 map. Out of 245 survey points, 157 were located in forest and 88 in non-forest. The 2001 classification had an overall accuracy of 92.6%. Ground-truthing points and aerial photos are not available for other years, but the 2001 analysis is an indicator of my overall ability to classify forest cover correctly for the study area.

After classifications were completed, Landsat MSS and the ASTER classifications were resampled to a cell size of 30 m to allow for integration with the Landsat TM and ETM+ classifications. After resampling, all images were smoothed using a 3 x 3 cell majority filter to reduce noise. This type of filter uses a moving window of 9 cells to determine whether the center cell value will be changed to match surrounding cells. If there is a majority of one value within the 9 cells then the center value is replaced with the majority value. I used GIS to overlay the classifications and determine deforestation between time periods and to assess the spatial and temporal dynamics of these changes. I produced deforestation maps for each period and one for overall forest loss from 1972 to 2005. My maps incorporated the following categories: 1)

Non-change classes or categories that remain under the same land cover type for both time steps being compared, including: a) forest—all areas with more than 30% canopy cover; b) water—lakes, reservoirs, rivers and streams; and c) non-forest—all other areas; 2) Change classes, including: (a) deforestation—non-forest or water areas that were classified forest in the previous time step; (b) regrowth – forested areas that were non-forest in the previous time step.

Assessing Error Resulting from Different Spatial Resolution in Satellite Data

Availability of satellite data for my study area is limited and I had to include imagery from different sensors with varying characteristics. Perhaps the greatest challenge is to determine whether differences in spatial resolution (MSS, 60 m; TM/ETM+, 30 m; and ASTER, 15 m) affected estimates of deforestation rates. Since the majority of satellite images used in the study were recorded at a 30 m spatial resolution, I used that as the base resolution for all analyses. This allowed me to retain the greatest amount of detail—keeping three out of five images at their native resolution—while not biasing the results significantly towards the finer or coarser resolution data sets.

To assess the possibility of bias caused from the varying spatial resolutions, I conducted a control study. First I resampled the 1989 Landsat TM image to 60 m, then classified it and calculated change from the 1973 Landsat MSS classification. Similarly, I degraded the resolution of the 2005 ASTER image to 30m, classified its land cover, and compared it to the 2001 Landsat ETM+ classification. I found that resampling the Landsat TM resulted in a 7% higher deforestation (0.22% difference in annual rate) while the resampled ASTER resulted in 1% lower deforestation (0.03% annual difference).

Since using the original resolution gives a more conservative deforestation estimate for Landsat MSS to Landsat TM change and results in only 1% difference for the Landsat ETM+ to ASTER change, I based my classifications on original imagery resolutions in all cases. After the classifications were completed, I resampled the 1972 and the 2005 images to 30 m for analysis.

Land Cover Change Index

To explore spatial deforestation dynamics, I developed a land cover change index ranging from 0 to 4, indicating the number of changes that occurred between the acquisition dates of the five satellite images. Based on this data set I analyzed spatial and temporal patterns inside and outside the sanctuary. By combining the land cover change index map with land cover maps for 1973 and 2005, I identified how land use changes were driving land cover changes, specifically deforestation. The assumptions for this analysis were as follows:

a) Areas forested in 1973 and experiencing one change to non-forest by 1992 are considered permanently converted to agricultural areas or associated village areas.
b) All forested areas experiencing more than one change to non-forest or changing to non-forest after 1992 are considered to be shifting cultivation.
c) Non-forest areas that changed to forest at least once between 1973 and 2005 are considered to be shifting cultivation.
d) All forest and non-forest areas that experienced a single change or multiple changes to water during any time period were classified as flooded or as floodplains.

Protected Area Effectiveness

One measure for the effectiveness of protected areas is their ability to retain their original land cover (Bruner et al. 2001) especially in landscapes where areas outside the protected areas are experiencing rapid degradation and land cover changes. To assess CWS's effectiveness, I calculated overall deforestation rates but also assessed forest losses and deforestation rates within 1 km wide buffers reaching from the boundary to the center of the sanctuary.

RESULTS

Temporal Deforestation Dynamics and Forest Losses

Declines in forest cover in the study area were high between 1973 and 2005 (Table 3.2, Figure 3.2). In 1973 over 70% of the landscape was dominated by forest cover but within 32 years forest cover had declined to less than 30% of the entire study area. Forest losses were highest outside CWS where forest cover was reduced to just over 23% of the land area by 2005.

Deforestation rates inside and outside Chatthin Wildlife Sanctuary explain these patterns and illustrate the temporal dynamics of land cover change (Table 3.3, Figures 3.2 and 3.3). About 1,688 km^2 (62%) of forests were lost in the study area since 1973 and the total annual deforestation rate of 1.93 % is well above the global average. However, even this high overall deforestation rate is probably an underestimate influenced by a longer period of relatively lower deforestation between 1973 and 1989. Inter-period deforestation rates are generally much higher and show a continuous increase from

1.86% in 1973 to 5.56% in 2001 (Table 3.3). After 2001 only about 1,000 km^2 (26%) of forest remained in the area and, probably as a consequence, deforestation slowed slightly but still remained at high levels of 3.68%. Regrowth to forest in the study area was minimal compared to deforestation rates (Table 3.3 and 3.4). As forests declined in the area, CWS increasingly became a forest island surrounded by agriculture and water reservoirs (Figure 3.3).

Table 3.2. Changes in forest area at Chatthin Wildlife Sanctuary (CWS) and the surrounding landscape between 1973 and 2005.

	Inside		Outside		Total	
Year	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
1973	333	92	2405	69	2738	71
1989	310	85	1734	50	2044	53
1992	296	81	1624	46	1920	50
2001	281	77	720	21	1001	26
2005	286	78	806	23	1092	28

Table 3.3. Deforestation inside and outside Chatthin Wildlife Sanctuary (CWS) between 1973 and 2005.

Period	Deforestation area (km^2)			Percent deforestation			Annual deforestation rate (%)[1]		
	Inside	Outside	Total	Inside	Outside	Total	Inside	Outside	Total
1973-1989	30	785	815	9	32	30	0.57	2.04	1.86
1989-1992	22	281	303	7	16	15	2.31	5.41	4.94
1992-2001	29	932	961	10	57	50	1.09	6.38	5.56
2001-2005	13	134	147	5	19	15	1.17	4.66	3.68
1973-2005	53	1636	1688	16	68	62	0.49	2.13	1.93

[1] Calculated as net deforestation rate where regrowth between time periods offsets forest losses.

Table 3.4. Regrowth forest inside and outside Chatthin Wildlife Sanctuary (CWS) between 1973 and 2005.

Period	Regrowth area (km^2)			Percent regrowth			Annual regrowth rate (%)[1]		
	Inside	Outside	Total	Inside	Outside	Total	Inside	Outside	Total
1973-1989	7	115	122	21	10	11	1.32	0.65	0.67
1989-1992	8	171	179	15	10	10	2.97	3.23	3.28
1992-2001	13	28	42	20	2	2	2.20	0.17	0.24
2001-2005	18	220	238	22	8	8	5.39	1.97	2.07
1973-2005	5	36	41	16	3	4	0.49	0.10	0.11

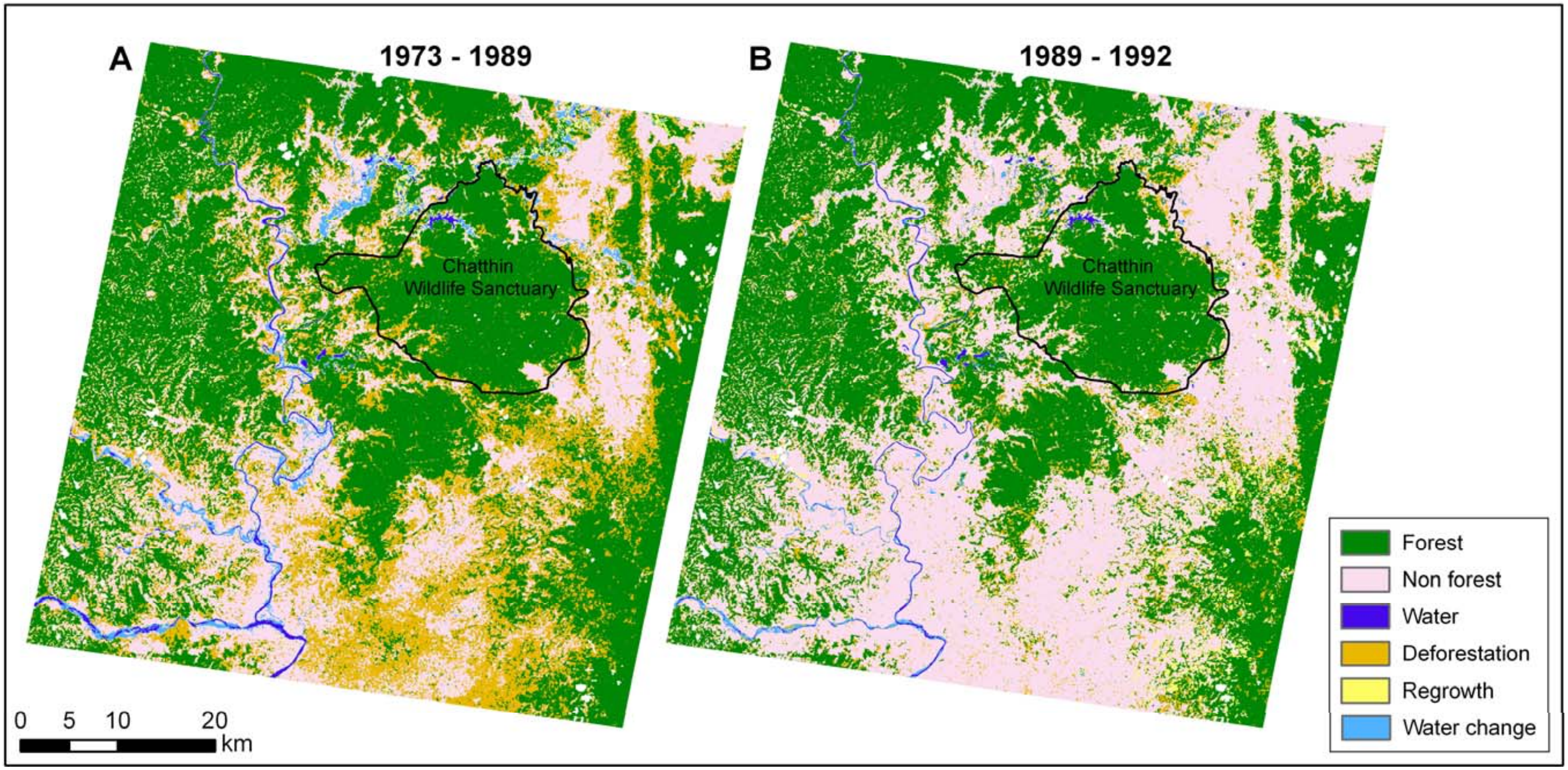

Figure 3.2. Temporal and spatial deforestation dynamics. Land cover change analyses for each time period. A = 1973 to 1989; B = 1989 to 1992; C = 1992 to 2001; D = 2001 to 2005. Forest, Non-forest, and Deforestation categories represent areas that did not change during the study period.

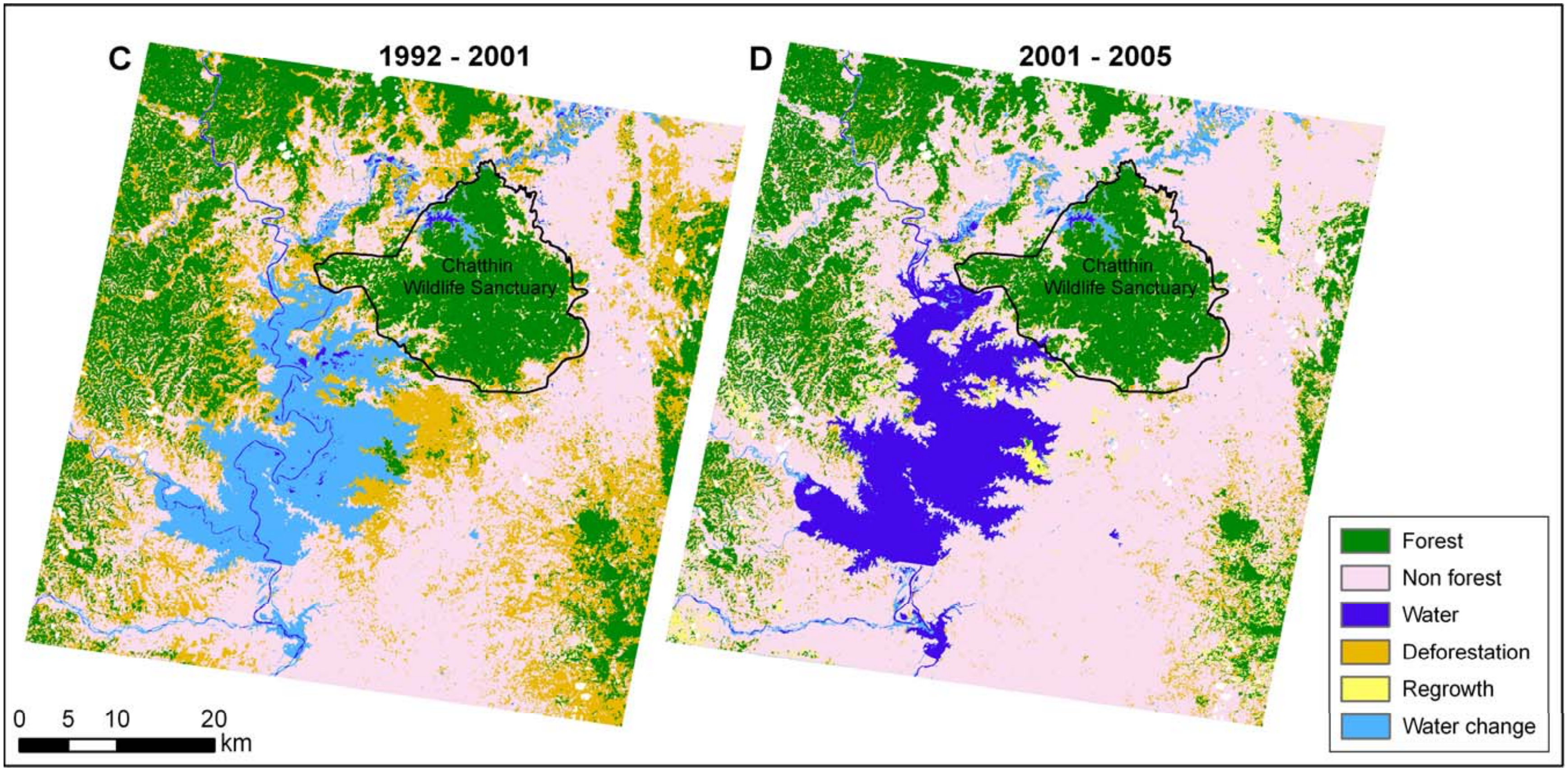

Figure 3.2, cont'd.

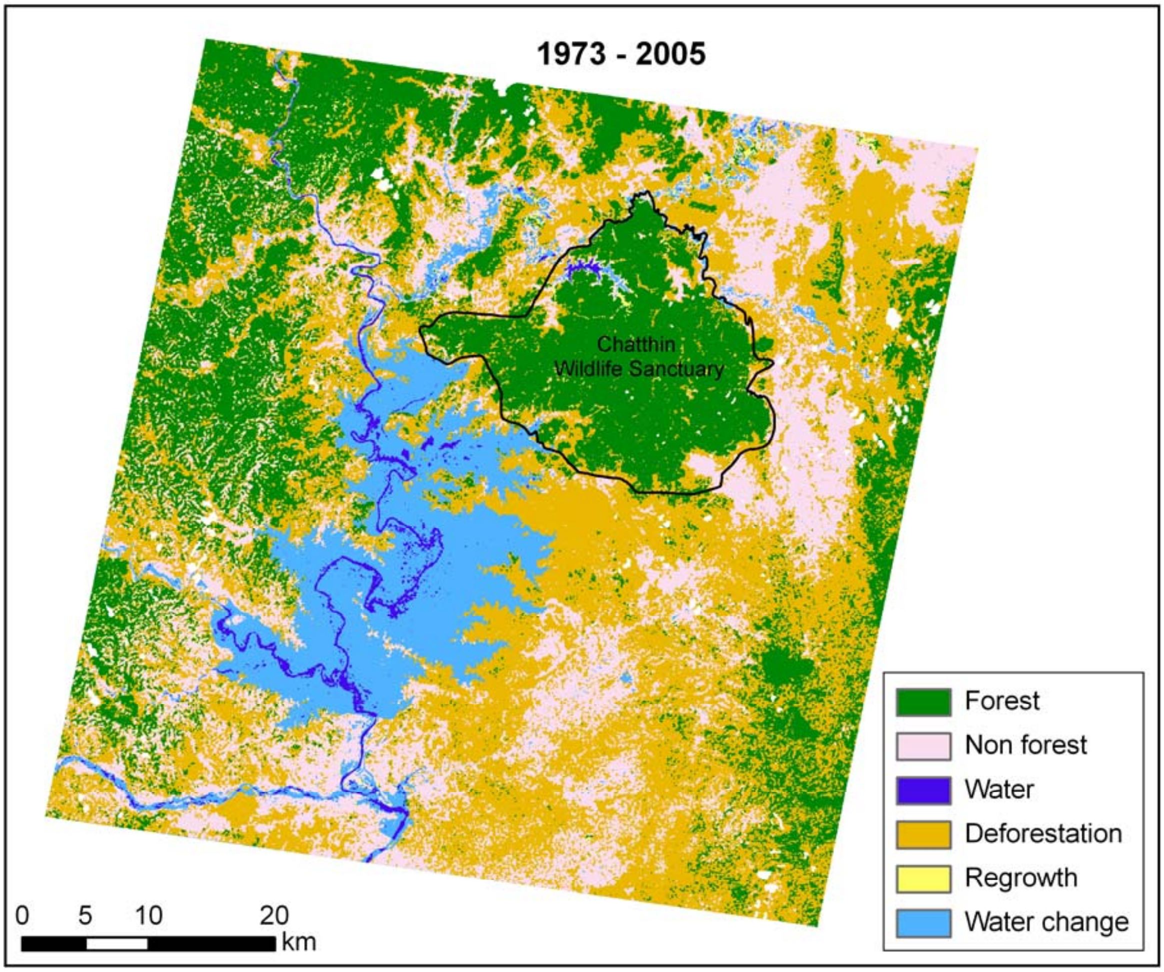

Figure 3.3. Overall land cover change between 1973 and 2005.

Deforestation was most severe outside CWS (Table 3.3, Figure 3.3), with annual rates ranging from 2.04% to 6.38%. Forest losses were also considerable inside CWS, with net annual deforestation rates well above the global average of 0.2%. However, the difference between inside and outside deforestation rates is dramatic, with the latter being higher by several magnitudes (Table 3.3). Regrowth rates were also higher inside CWS compared to outside (Table 3.4). Temporal patterns in deforestation rates were variable inside the reserve; the greatest forest destruction occurred between 1989 and 1992 when deforestation rates briefly went up to about 40% of outside rates, but they declined afterwards.

Spatial Deforestation Dynamics and Land Cover Change

Based on the analysis of my land cover change index, most of the area (61%) experienced at least one change in land cover between 1973 and 2005 (Table 3.5, Figure 3.4A). The majority of these changes were unidirectional; a change occurred only once and was permanent. Relatively little change occurred inside CWS; almost three-quarters of the sanctuary remained unchanged over time.

Conversion of forest to agriculture was the most important driving force for deforestation in the study area (Table 3.5, Figure 3.4B). Almost one-third of all land experienced this change once and subsequently never returned to forest. However, shifting cultivation and flooding also affected large portions of the land. Most of the flooding occurred between 1992 and 2001, when Thapanseik Dam was built. The flooding affected approximately 420 km^2 of forest and cropland within the study area. Additional flooding occurred along streams and rivers in the area. Only 21% of the entire study area remained under forest cover and was never affected by a land cover change that I could detect (Table 3.6, Figure 3.4B). This number is lower than the forest cover listed in Table 3.2 for 2005, because it excludes regrowth areas from previous time periods and focuses on unchanged and presumably fairly intact forest areas.

Table 3.5. Land cover change index describing the number of land cover changes inside Chatthin Wildlife Sanctuary (CWS) and outside its boundaries between 1973 and 2005.

Change index[1]	Area (km^2)			Percent		
	Inside	Outside	Total	Inside	Outside	Total
0	271	1243	1514	74	35	39
1	48	1603	1650	13	46	43
2	30	450	480	8	13	12
3	13	184	196	4	5	5
4	2	26	28	1	1	1

[1] The land cover change index was calculated by summing the changes occurring for each pixel during each time step for a maximum of four changes.

Table 3.6. Land use changes associated with deforestation between 1973 and 2005.

Land use/land use change[1]	Land cover 1973	Land cover changes	Area (km^2)	Percent
Areas with land use change				
Agricultural conversion	Forest	1	1256	32
Shifting agriculture	Forest/Non-forest	1 to 4	593	15
Flooded/floodplain	Forest/Non-forest/Water	1 to 4	512	13
Areas with no land use change				
Forest	Forest	0	816	21
Agriculture	Non-forest	0	686	18
Water	Water	0	11	<1

[1] Land use change categories are defined as: a) agricultural conversion = areas characterized by a unidirectional change from forest to non-forest by 1992; b) shifting cultivation = areas starting as forest or non-forest and changing land cover more than once, or areas that changed after 1992; c) flooded/floodplain = areas with at least one change and classified as water at least once.

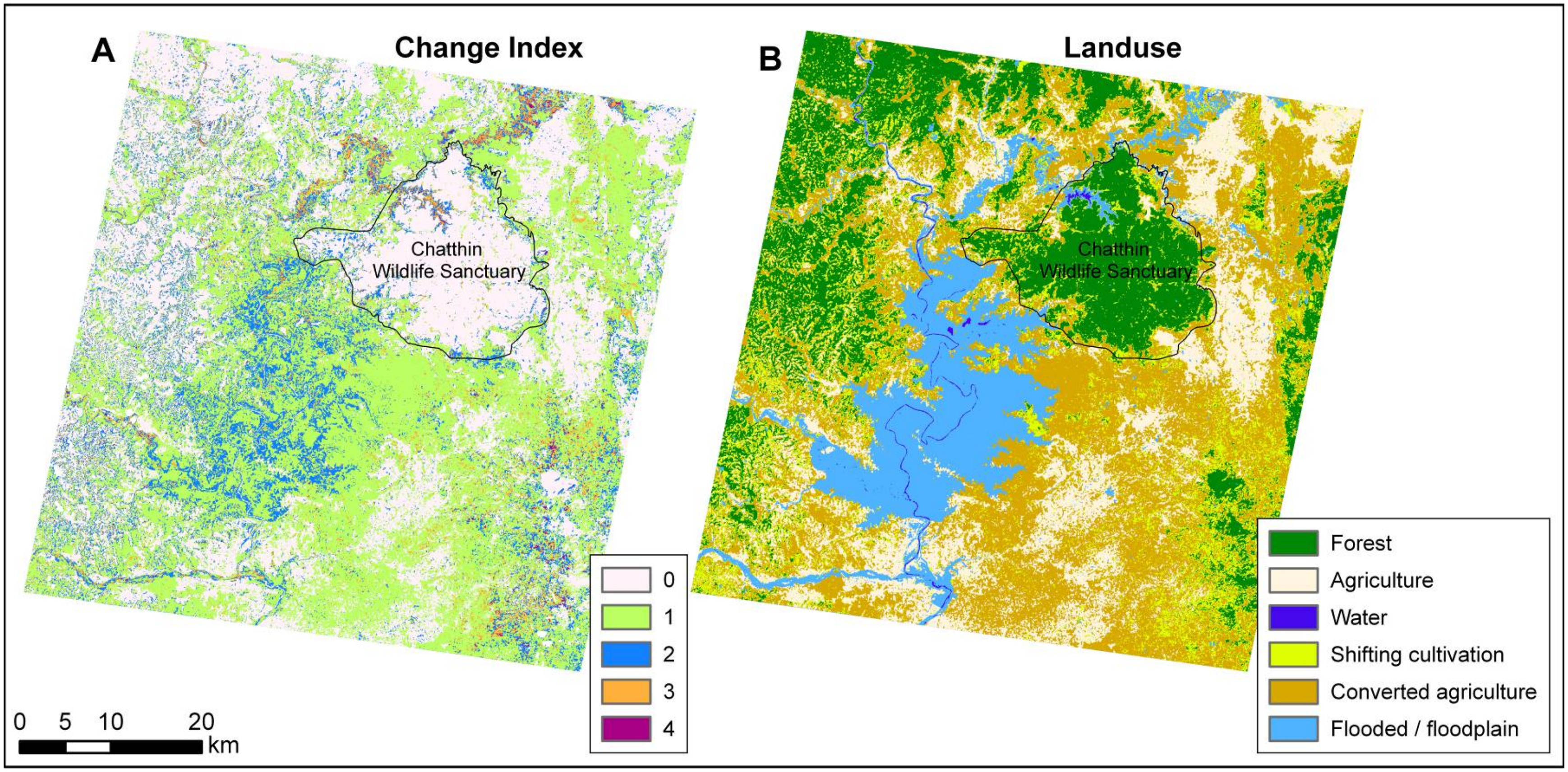

Figure 3.4. Land cover change index and land use changes that are driving deforestation. A: Change index representing number of land cover changes occurring at each pixel throughout the study; B: Land use change associated with deforestation. Land use change categories: a) agricultural conversion = areas characterized by unidirectional change from forest to non-forest by 1992; b) shifting cultivation = forest or non-forest areas changing cover more than once, or areas that changed after 1992; c) flooded/floodplain = areas with one or more changes to water.

Patterns of land use changes that affected deforestation are different inside and outside CWS (Figure 3.4B). Shifting cultivation is proportionally more prevalent inside CWS (12% versus 9% for agricultural conversion). Almost all agricultural conversion inside CWS is limited to boundary areas (Table 3.7) or in proximity to villages grandfathered into the sanctuary.

The most severe forest losses inside CWS occurred within only 1 km of the sanctuary boundary (Table 3.7). These impacts declined sharply, moving inward from the boundary. All areas of CWS beyond 5 km from the boundary experienced deforestation rates well below the countrywide or even global averages of 0.2% annually.

Table 3.7. Deforestation as a function of distance from the sanctuary border inside Chatthin Wildlife Sanctuary (CWS) between 1973 and 2005.

Buffer	Area	Forest		Deforested		Annual deforestation rate
distance (m)	(km^2)	(km^2)	(%)	(km^2)	(%)	(%)
Outside[1]	-	769	32	1636	68	2.13
1000	87	44	60	29	40	1.24
2000	71	53	84	10	16	0.51
3000	55	43	86	7	14	0.44
4000	46	41	93	3	7	0.22
5000	38	35	95	2	5	0.15
6000	30	28	97	1	3	0.11
7000	21	21	99	<1	1	0.04
8000	13	12	98	<1	1	0.06
9000	4	4	99	<1	1	0.03

[1]Outside = entire study area beyond the boundaries of the CWS rather than a particular buffer distance.

DISCUSSION

Dry Forest Losses and Driving Forces

Deforestation is rapidly changing the landscape around CWS. My findings support other studies showing that Myanmar's dry forests are among the most threatened and least protected forest ecosystems in the country (Koy et al. 2005; Leimgruber et al. 2006; Chapter 2). Temporal patterns of deforestation indicate that the highest rate of forest loss occurred during the 1990s. However, flooding in 2000-2001 from a hydroelectric dam project has also caused major changes in land cover and land use. This dramatic loss of dry forests observed around CWS is representative of dry forest declines throughout Myanmar (Leimgruber et al. 2006) as well as other countries in the region (DeFries et al. 2005).

Agricultural conversion was the most important driving force for deforestation around CWS. In my analysis, this type of land use change was represented by a one-time, irreversible replacement of forest with non-forest land. Swift and extensive land cover/land use changes were accelerated by a quest for more agricultural land (Myint Aung et al. 2004), partly to feed the growing populations, but also as result of government policy (Eberhardt 2003). The government has encouraged agricultural expansion and even the export of rice as a means of generating revenue (McShea et al. 1999). In 1987-88 the Myanmar Agricultural Enterprise started encouraging people in the area to plant sugar cane, mostly to meet demands for sugar coming from China, India, and Thailand (Myint Aung et al. 2004). Sugar cane is worth 2-3 times more than crops usually planted in the area, and this campaign encouraged a new influx of people intent on planting sugar cane. The expansion of sugar cane production has had additional indirect effects on the forest because it requires a great deal of fuelwood for processing, leading to an increase in demand for fuelwood along with the spread of sugar cane crops.

The next important process changing the land cover is that brought about by shifting cultivation. In Myanmar, shifting cultivation is integral to the local culture and has developed through long tradition (Eberhardt 2003). The practice of shifting cultivation allows areas to go fallow and they may return to forest before they are used again for growing crops. A mix of permanent agriculture with shifting cultivation, often supplemented by livestock management, is characteristic for Myanmar as well as for other countries in the region (Menzies 1995, cited by Eberhardt 2003; Eberhardt 2003). However, rapidly growing populations and demands for agricultural products have increased rotation cycles beyond what is sustainable and in many places and has also resulted in the transition to permanent agricultural practices (Eberhardt 2003; Leimgruber et al. 2006). This process is also driven by governmental strides towards achieving more widespread land registration, which often also results in moving the land into the control of large agribusiness ventures (Eberhardt 2003). If the trends observed in my analysis continue, it seems likely that much of the land currently under shifting cultivation will transition into permanent fields.

Hydroelectric development is another major force of deforestation in my study area and, together with the construction of irrigation dams, probably has increasingly affected forests elsewhere in Myanmar. Between 1988 and 2002 at least 23 hydroelectric dams and 129 irrigation dams were constructed throughout the country (Myanmar's Ministry of Information 2002, cited in Eberhardt 2003). The negative environmental consequences of these dam developments have been pointed out in a region-wide analysis (Hirsch 1995, cited by Eberhardt 2003), but little information currently exists about how dam developments are affecting forests, and in particular dry forests, by directly converting forest to floodplains. My study showed the highest overall deforestation rates during the time period of the dam construction and flooding.

There are cascading land conversion effects when villagers from affected areas move, rebuild their homes, and acquire new fields. The construction of Thapanseik Dam forced the relocation of 52 villages (Myint Aung et al. 2004). Villagers were given very little compensation for the loss of their cropland and homes. Though the dam was located 20 km to the south of CWS, 6 new villages relocated right along the southwestern boundary of the sanctuary. Many households had few economic assets before the flooding and, due to the move, afterwards had to rely even more heavily on forest resources for fodder and other forest products (Myint Aung et al. 2004). The flooding, and preceding logging of forests, removed a 165 km^2 reserve forest located just south of the sanctuary that potentially could have provided additional habitat for the endangered Eld's deer in the region.

Spatial and Temporal Dynamics of Deforestation at CWS

Spatial and temporal deforestation patterns inside CWS are consistent with the feedback loop of expanding agriculture and increasing extractive pressures on remaining forest resources, with forest cover of CWS steadily decreasing through the study period. Forest losses in CWS have so far occurred mostly along the sanctuary's boundaries, with steadily less deforestation occurring towards the interior. Most of this deforestation can be attributed to extraction of fuelwood and building materials rather than to shifting cultivation and agricultural conversion (Chapter 4). The latter two land uses are prevented by ranger patrols and all farmers that attempt to encroach on sanctuary forests are expelled. However, fuelwood collection and extraction of building materials, although discouraged by ranger patrols cannot be completely controlled (Myint Aung et al. 2004).

The spatial patterns observed at CWS indicate that even a “paper park” may be far better for the protection of forest resources than no park at all. CWS has a long and varied management history and for much of this history would have to be considered as having been a paper park, with little active management or protection (Myint Aung et al. 2004). Though deforestation rates reached their highest levels between 1989 and 1992 when pressures from the outside increased and little active protection existed, the rate of loss during those three years was still only 40% of that observed outside the sanctuary. Also important is that once legal protection for an area is established, staff from the responsible government agencies has authority to manage the area and actively prevent forest loss and degradation. On lands outside protected areas this can only be achieved via incentives and new land management strategies that provide clear benefits to local communities. However, such incentives and strategies can prove difficult to implement on such lands.

Temporal patterns of forest loss and encroachment at CWS suggest that collaborative and international conservation projects have enhanced protection efforts at CWS. In collaboration with the Wildlife and Nature Conservation Division of the Myanmar Forest Department, in 1992 the Smithsonian’s Conservation and Research

Center initiated ecological studies of the Eld's deer, along with biodiversity inventories and ranger training programs at CWS (Wemmer et al. 2004). The project, made possible through outside support and funding, had immediate impacts on CWS management (Myint Aung et al. 2004). The majority of CWS staff moved into the sanctuary. Rangers conducted regular wildlife surveys, dramatically increasing the presence of rangers present throughout the sanctuary. In addition, active ranger patrolling was initiated to reduce negative impact on CWS resources from encroachment and forest use. The CWS boundary was recorded using GPS and marked for better onsite identification by both sanctuary staff and local people. Prior to this deforestation rates inside CWS had risen sharply between 1989 and 1992, reaching the highest levels (of inside-park deforestation) of any interval during the study period (2.31% annually). However, from 1992 to 2001 deforestation rates dropped by more than half (1.09 %). At the same time, deforestation occurring outside the sanctuary increased to the highest level of any interval of the study period (6.38%), providing evidence that the increased patrolling and staff presence inside the sanctuary did help decrease deforestation.

IMPLICATIONS FOR CONSERVATION

Monitoring Change via Satellite Imagery

Satellite monitoring provides new tools for assessing the effectiveness of protected areas in preserving land cover (Zheng et al. 1997; Foody & Cutler 2003; Curran et al. 2004; Linkie & Smith 2004; Maselli 2004; DeFries et al. 2005; Trigg 2006). In this study I was able to detect temporal and spatial patterns of land degradation inside and outside CWS.

Increased temporal resolution for satellite monitoring of protected areas, by way of comparing multiple images from different dates, proves extremely useful not only to record land cover change but also to investigate potential land use changes that might be driving the deforestation or the degradation of other land cover types. These patterns correlated with information on the ground (Chapter 4) and demonstrated that in my case study, increased use of forest resources may be impacting the sanctuary, particularly as the landscape outside becomes denuded of forests

Satellite imagery can only portray information on land cover, but cannot gauge actual levels of biodiversity. Especially in small protected areas that are surrounded by developed land and that are easily accessible, biodiversity can be affected by forest resource uses ranging from fuelwood collection and other extractive activities to poaching of plants and wildlife. The concept of “empty forests” or loss of animals within intact forests (Redford 1992; Brashares et al. 2004; Fa et al. 2005; Refisch & Kone 2005) is well established elsewhere and points to the necessity for conducting actual biodiversity surveys, supplemented by hunting and market surveys to establish a protected area’s effectiveness at preserving biodiversity. However, satellite mapping surveys are often more feasible than ground surveys because they are cheaper and can be readily conducted even for areas inaccessible for geographic or even political reasons. These remote monitoring techniques can provide a first assessment, offering initial insights not only into the intactness of the protected area’s land cover, but also regarding its accessibility and the risk for increased extractive activities.

Protecting the Remaining Dry Forests of Myanmar

Establishing legal protection is the first important step for maintaining the few remaining dry forest patches. Most of the dry forest area remaining in Myanmar, apart from CWS, is in the more mountainous areas less preferred for agriculture. Yet, as pressures increase, these remaining dry forest areas will likely decline as well. I have found little indication that agricultural conversion can be reversed, even in the case of shifting cultivation, which, when it occurs today, is likely a transitional phase that will eventually move toward permanent conversion. Helping people become less dependent on forests and finding ways to mitigate the impacts of fuelwood extraction could potentially slow the decline of dry forest cover.

CWS continues to be in a precarious position both physically and politically. While protection has been effective in slowing deforestation inside the sanctuary, it has not stopped it entirely. Beyond the basic issues of park management are struggles between government officials with different objectives who are competing for resources, a common problem in Myanmar (Eberhardt 2003). For example, in 1998, soon after the CWS warden received permission to add a 59 km^2 buffer zone along the southern boundary of the sanctuary, township officials began a large scale project to have this buffer area converted to an agricultural area. Responding to complaints from the warden, the Divisional Commander in the area put a stop to the project (Myint Aung et al. 2004). However, a wide road constructed into the center of the buffer zone for the project is still visible on Landsat and ASTER images of the area, and presumably enhanced buffer zone access for local populations. The differing priorities of various government ministries and the lack of land use planning leave in doubt the long-term prospects for protection of CWS and other dry forest areas.

The loss of most of the dry forests surrounding CWS will likely have significant consequences for Myanmar's biodiversity. CWS and surrounding areas have recently been identified as constituting one of several priority areas for biodiversity conservation in Myanmar (Tordoff et al. 2005). These dry forest areas may have provided prime habitat for critically endangered species, including the Burmese star tortoise (*Geochelone platynota*), the white-throated babbler (*Turdoides gularis)*, hooded treepie (*Crypsirina cucullata*), the Burmese bushlark (*Mirafra microptera*), two endangered primate species, the hoolock gibbon (*Bunipithecus hoolock*) and capped leaf monkey (*Trachypithecus pileatus*), as well as other endangered species including gaur (*Bos gaurus*), banteng (*Bos javanicus*), elephant (*Elephas maximus*) and tiger (*Panthera tigris*) (Tordoff et al. 2005). Similarly, the Eld's deer has an affinity for large dry forest patches (McShea et al. 1999) and the species likely has declined as a consequence of the observed forest losses. Further loss of these already rare forests will not only reduce the chances for survival of Eld's deer and other wildlife and adversely impact the ecosystem, but will also represent a loss for the people who are closely tied to these forests.

Chapter 4: The Impact of Local Communities on a Dry Forest Sanctuary: A Case Study from Upper Myanmar (Burma)

ABSTRACT

Tropical dry forests are more degraded and threatened than rain forests but receive less conservation attention. Most conservation policy and efforts are directed toward tropical rain forest protection. Typically dry forests are surrounded by dense human populations and are subject to higher extraction pressures than most other natural ecosystems. I studied the use of forest products by local communities living in and around a dry forest sanctuary in Myanmar (Burma) to identify potential solutions for future management and conservation. I surveyed 784 people in 28 subsistence-based agricultural communities around Chatthin Wildlife Sanctuary. All but a few households depend on the sanctuary for fuelwood, food, medicine, and housing materials. I found that poverty and the overall socioeconomic situation are the driving forces behind the extraction of forest products. Fuelwood was the most important household resource extracted from the forest. Based on my results, I make recommendations for management and present ideas for development strategies that may improve people’s livelihoods, such as using fuel-efficient stoves, implementing community forestry programs, and developing means for deriving alternative protein sources.

INTRODUCTION

Tropical dry forests are less common, more degraded, and proportionately more threatened than rain forests (Janzen 1988; Wilson 1992). Yet these forests receive little attention from the conservation community, and most research, policy, and conservation efforts are directed toward rain forest protection (Janzen 1988; Wilson 1992; Bullock et al. 1995). Though tropical dry forests have lower levels of biodiversity, they are important habitats for many endangered species, have unique ecological and physiological adaptations, have greater diversity of life forms than their wet forest counterparts, and provide essential ecosystem services to people living nearby (Stott 1990; Bullock et al. 1995; Gentry 1995; Medina 1995).

Conventional protected area strategies, are not likely to succeed in conserving the last tropical dry forests, because frequently these forests are found in areas that are densely populated, have fertile soils, and lie on low elevation and low-relief topography allowing irrigation (Bunyavejchewin 1982; Maass 1995). Higher human population levels result in higher extraction pressures and greater threats to these dry forests habitats (Murphy & Lugo 1986; Bullock et al. 1995). Murphy and Lugo (1986) estimate that globally as much as 80% of wood extraction from tropical dry forests is used for the purposes of cooking and heating rather than for timber. Other important products include medicines, rubber, cork, resin, cooking oils, wild game, fruit, nuts, and materials for shelter (Murali et al. 1996; Stott 1990).

Even dry forest areas that are protected frequently experience high levels of use (e.g., Myint Aung et al. 2004). Understanding resource requirements and uses in local communities adjacent to remaining tropical dry forests is essential for developing strategies for sustainable use and long-term conservation of these ecosystems.

To examine these issues I have selected Chatthin Wildlife Sanctuary (CWS), Myanmar for a case study. Like other tropical dry forest protected areas, CWS faces intense pressures from surrounding communities. Over the last century, land cover in and around CWS was converted from intact tropical dry forest into a mosaic of degraded second growth forest (Myint Aung et al. 2004; Chapter 3). Most large mammals and all top predators have disappeared from the area during the last 20 years, making it more accessible for grazing and forest product extraction. Increased law enforcement, research and training activities, and transfer of many staff from headquarters located 35 km away to inside the park began during the 1990s. However, despite increased patrolling, efforts to limit encroachment, and community outreach, the forest continues to be degraded (Myint Aung et al. 2004). I conducted a comprehensive study of resource use of local communities to determine why the degradation of CWS is continuing. Specifically, I address the following research questions:

1) How do local people use forest products at CWS?
2) Which essential household needs drive forest product use?
3) What factors characterize households with the highest levels of forest product use?

METHODS

Study Area

Chatthin Wildlife Sanctuary covers 362 km^2, including a buffer zone of 53 km^2 bordering its southern boundary (Figure 4.1). It is located on the northern edge of the central dry zone (95^0 24'E—95^0 40'E, 23^0 30'N—23^0 42'N), which has the highest population density in the country. Historically, the central dry zone was dominated by forest (Kurz 1877; Stamp 1925) but has mostly been converted to agriculture. The climate is monsoonal, with 3 seasons, including the rainy season (~0.4 m rainfall annually), the cool-dry season, and the hot-dry season (Myint Aung et al. 2004). Crops are grown for half the year, August through January. During the dry seasons the area burns, fires are precipitated by both human and natural causes, and green shoots begin to appear soon after burning. The sanctuary consists primarily of dry deciduous forest, known in Myanmar as "Indaing" forest. It is dominated by the dipterocarp species *Dipterocarpus tuberculatus*, with some evergreen forest and grassland scattered throughout the Indaing.

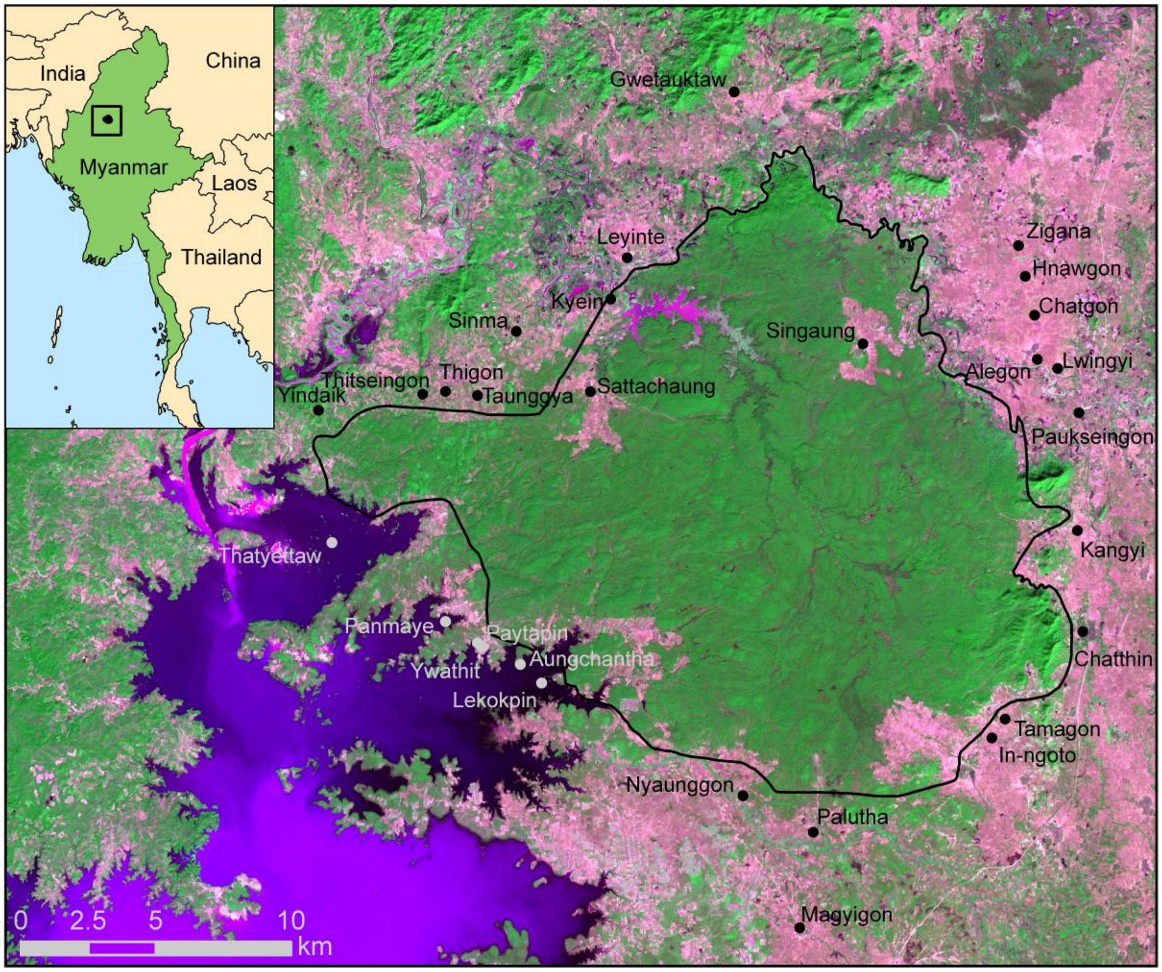

Figure 4.1. Villages in and around Chatthin Wildlife Sanctuary. Background: ASTER satellite imagery acquired January 2005. The black line indicates the sanctuary boundary. Light green represents forest, dark blue and red are flooded areas, and light purple represents rivers and small lakes. ASTER image acquired January 2005 (color display: red = band 2, green = band 3N, blue = band 1).

CWS has a long environmental and political history; it is one of the oldest parks in Myanmar and is described in detail by Myint Aung et al. (2004). It started out as a fuel reserve in 1919 under British rule and was gradually transformed into a sanctuary to conserve the endangered Eld's deer (*Cervus eldi*). Active management of the sanctuary did not begin until 1955 and staff consisted of one person until the early 1970s. Gradually sanctuary staff increased up to the current level of more than 70 people. The area is accessible only by a dirt road leading from the nearby railway station and during the rainy season it can only be reached with a tractor. The three villages located inside the sanctuary boundaries have been "grandfathered" into the reserve. In addition there are 31 other villages within 10 km of the sanctuary, including approximately 4,000 households and over 25,000 people. A buffer zone was established in the 1990s, further protecting parts of the sanctuary. Buffer zone management follows the same criteria as sanctuary management.

Villagers in the area are primarily farmers (82%), with some wage laborers (11%) and fishermen (3%). Households average 2.4 ha of land (median = 3 ha) and the average monetary household income is $579/year (median $421/year), ranging from 0 to $10,316/year per household. Education levels on average are low (3.1 in a Myanmar government standard system of 1-10 levels) (see Appendix A for demographic and socioeconomic village data).

Survey Design and Sampling

In 1999, a Smithsonian Institution research team conducted attitude and economic surveys to assess local people's perceptions of the protected area and its staff (Allendorf et al., submitted). I built on this initial work and added several components directed at assessing more specifically what products were being extracted and how extraction related to individual socioeconomic status. In 2003, I trained two schoolteachers from Chatthin village, Khaing Khaing Swe and Thida Oo, in survey methods. Teachers are ideal survey team members because they are well-known and respected in the community, and local people are less inhibited about talking openly with a teacher than with sanctuary staff member. Villagers agreeing to participate in the survey understood that the teachers were working with staff of CWS. They were also assured anonymity and that they could answer without fear of repercussions.

During June, July, and August 2003, the survey team conducted the interviews by randomly selecting households from lists provided by village chairmen from 28 villages in and around CWS. Using stratified-random sampling, the survey team then selected 2 females and 2 males from each of 7 predefined age groups for interviews about each household. Age groups were defined arbitrarily as follows: 18-25, 26-33, 34-41, 42-49, 50-57, 58-65, and > 65. The average age of survey respondents was 43 years and ages ranged from 18 to 84 years. There were 107 respondents aged 18-25, 118 aged 26-33, 158 aged 34-41, 148 aged 42-49, 104 aged 50-57, 74 aged 58-65, and 75 over age 65. Interviewers asked questions and recorded answers in Burmese during the 1-hour interviews. Later they translated the answers to English, recorded them in a spreadsheet, and categorized qualitative responses for statistical analysis.

Most questions were open-ended, with some fixed response questions included (Appendix B). Some questions were directed toward the respondent, such as information regarding their age, gender, occupation, education level, and how many times they visited the forest each month. Most questions were designed to cover household information rather than information about the individual respondent. Interviews covered general information about the household, agricultural practices, use of forest products by the household, and household assets.

Forest Product Surveys

Respondents were asked to list household products and food gathered from the forest by members of their household, to note whether the products were collected inside or outside the sanctuary, and to estimate the level of the product's importance to the household (ranging from essential to unnecessary). To learn about the use of medicinal plants, the survey team questioned each respondent about types of plants they used for medicine, where these plants were collected, and how often the plants were used. To address wood extraction, the survey team asked what respondents used for cooking, where they obtained fuelwood (collected inside or outside the sanctuary, or purchased), how many cartloads of fuelwood they used each month, and how many housepoles they used each year. Questions about forest products covered hunting practices of the household, what animals were hunted, and where they were hunted.

The survey team requested information about foods the respondent's household had eaten the day prior to the interview and where each food item was obtained, i.e. from their own fields, their own livestock, purchased from the market, collected from the forest, or hunted. To investigate cooking habits, the interviewers asked how many times the household cooked each day, how much wood was needed, and how many hours fires were burned in the house during the rainy season, cool-dry season, and hot-dry season. The inquiries also included a query about whether households would be willing to use a stove rather than an open fire for cooking.

Only 19 households (2.4%) did not list any use of forest products. Since the use of forest products use was so pervasive I relied on two other factors to indicate high use levels. I considered households that had eaten something from the forest the day before the survey, and households that hunt inside the sanctuary, as having higher use levels than those that did not. The assumption that these two groups represent households with higher forest use levels is supported by results showing that each group averaged significantly higher numbers of visits to the sanctuary each month ($p = 0.000$, Table 4.1).

Socioeconomic and Demographic Surveys

People in rural areas in Myanmar often rely on trade of goods and products rather than solely on cash transactions. Therefore, to determine household wealth, I measured several household assets in addition to monetary income from wage labor, sales of crops or other goods. These assets included amount of land owned, amount of rice surplus, and number of livestock. To combine different livestock categories into one household asset, I calculated a “protein” score for each household, based on the average weight of different livestock species (FAO 2003). I multiplied the average weights by the number of each type of animal owned by the household and summed the totals.

Average households have 5 or 6 household members, all of whom tend to have little education and who rarely leave the villages in which they were born. Education levels are based on the government standard levels 1-10, which may be followed by university training, either through distance learning or by attending classes on a campus. Thirty-three percent of the respondents received their education through monasteries rather than the standard government system. I categorized this form of education as a 1.5 since it is the equivalent of the government's standard level 1 or 2. The majority of the people living around the sanctuary are Buddhists, with some Muslims and Hindus, the latter not exceeding 5% of the population.

Statistics

Most of the survey data were not normally distributed, even after various transformations. I used Kruskal-Wallis analysis of variance by ranks for comparing two groups, for example, to compare groups of households reporting a high level of forest product use with groups evidencing a low level of forest product use.

RESULTS

Household Use of Forest Products

Survey results show CWS communities depend on the sanctuary for fuelwood, food, medicine, and building materials (Figure 4.2). Almost all forest products are collected for direct use and represent essential subsistence items in these rural areas. Only 10% of respondents sell some of what they collect; the rest use all the items collected to meet their household needs. Over 44 forest products are used for food or other household needs (Appendix C). On a scale of 1-5, ranging from essential to unnecessary, most respondents ranked at least one of these products with a 1 (essential, 62%) or 2 (36%), and no products were considered unnecessary (Appendix C).

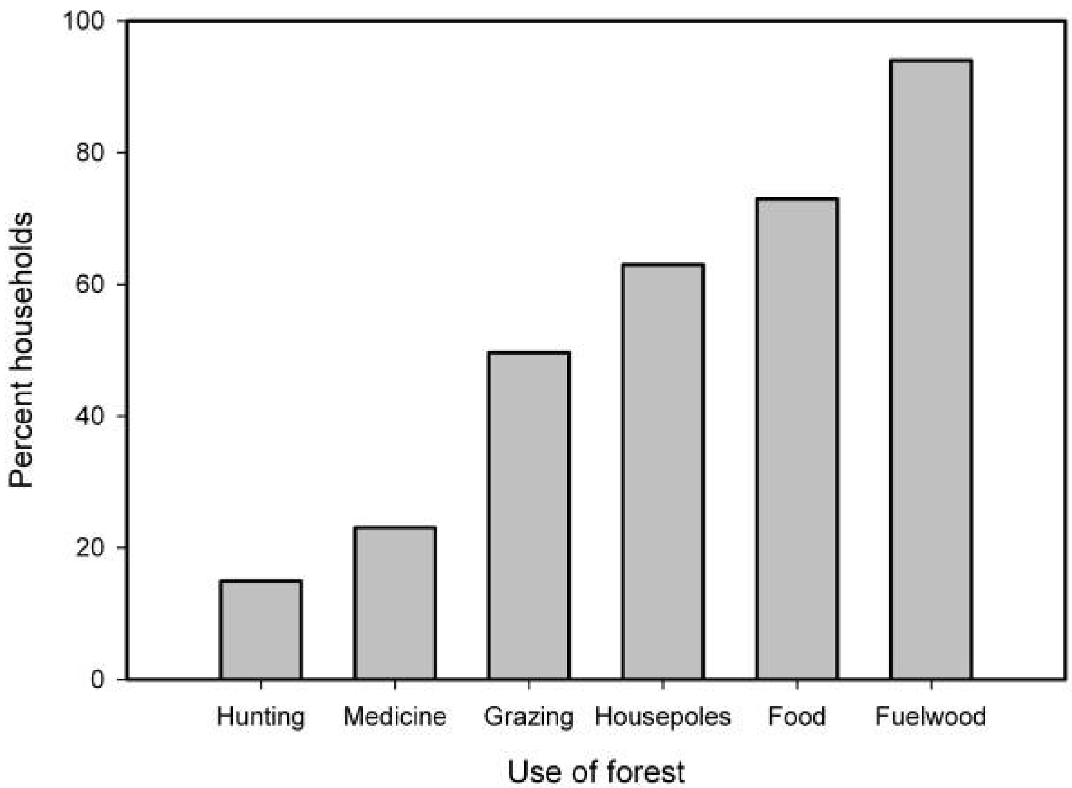

Figure 4.2. Use of Chatthin Wildlife Sanctuary forests by nearby households (*n*=784).

Hunting appears to be an important way for local residents to acquire additional protein. Over 34% of respondents confirmed hunting and fishing in the sanctuary or surrounding area by household members. A considerable number (14%) even admitted to illegal hunting and fishing inside the sanctuary, though this is likely underreported. Fish and frogs are major protein sources acquired through fishing and collecting (Figure 4.3A). At least 20% of the hunters also take medium-sized mammals such as muntjac, pangolin, rabbit, jungle cat and rat. No one admitted hunting the Eld's deer, though patrol staff members periodically apprehend people hunting the deer or find remains of a hunted deer. Other important forest uses include wood for house construction and grazing of livestock (Figure 4.2). Most families (96%) managed livestock, including an average of 3.4 cows, 1.5 buffalos, 2.4 pigs, and 9.7 chickens. Cows and buffalo are grazed primarily in paddy fields (78%), though some grazing occurs inside the sanctuary (14%) and buffer zone (40%), and 31% of these animals are fed purchased grain (Figure 4.3B).

Most households (75%) rely on the forests to provide food to supplement their harvest, with 8% reporting they never go to the market and rely solely on farming and forest products (Figure 4.3C). Forest foods are used so regularly that on the day of the interview, 41% of all respondents confirmed that someone in their household had eaten a forest product on the previous day. We identified over 70 different medicinal plant species during the interview survey, and 22% of all surveyed households collect at least one of these plants (Appendix D). Gathering of medicinal plants is mostly done inside the sanctuary (75% of households).

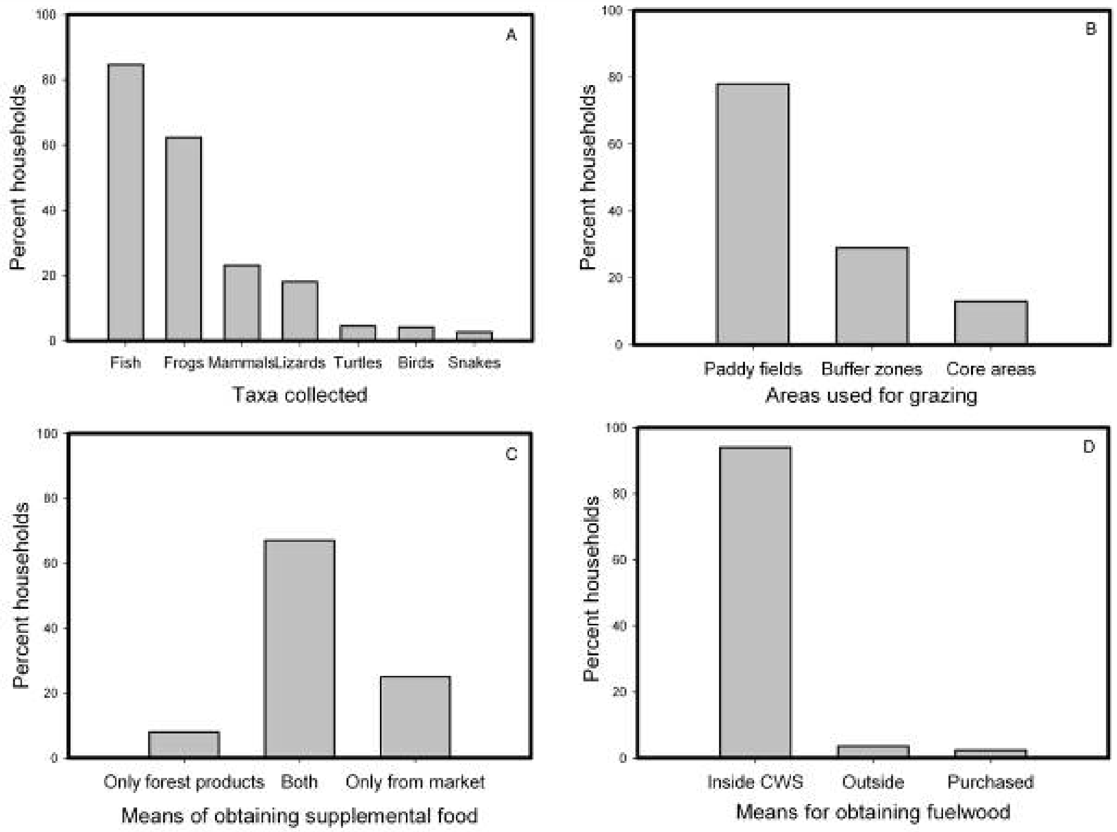

Figure 4.3. Summary of forest use inside Chatthin Wildlife Sanctuary: A: Protein sources from hunting and fishing; B: Locations used for grazing; C: Means of obtaining supplemental food; D: Means for obtaining fuelwood; *n*=784.

Socioeconomics of Forest Product Use

Socioeconomic conditions drive the use of forest resources in rural communities surrounding CWS. The villages are subsistence-based agricultural communities relying on surrounding forests to supplement frequently meager rice and livestock harvests. Just over half of all surveyed households either typically did not grow enough rice to support their members or grew just enough with no surplus.

Poor households with little education depend on forest products for subsistence (Table 4.1). Land owned and yearly income per household member were significantly lower for households that ate forest products the day prior to the survey or that indicated that they hunt inside the sanctuary than for other households (Table 4.1). All of these households also had significantly more rice shortages. In addition, hunting households were located in significantly closer proximity to the sanctuary than the others, and households that ate forest foods the day prior to the survey were significantly larger and had significantly lower education levels than other households. Not surprisingly, both hunting and forest food-consuming households visited the sanctuary significantly more often than other households.

Table 4.1. Factors affecting the livelihood of households that eat forest products or hunt inside Chatthin Wildlife Sanctuary. Statistics are based on Kruskal-Wallis One-Way Analysis of Variance.

Variable	**Mean**		**Mann-Whitney U statistic**	***p* value**
	High Use	**Low Use**		
		Hunting inside the sanctuary		
Household size	5.6	5.7	25 487.5	0.798
Household education level	3.3	3.5	26 947.0	0.203
Yearly income/household size	$96.37	$108.23	32 651.5	0.000**
Land/household size (ha)	0.498	0.550	29 953.5	0.029*
Livestock (kg)	1202	1152	24 839.5	0.546
Rice shortage/household size (bins)	8.4	6.8	22 583.0	0.050*
Distance (km) to sanctuary	1.20	1.94	32 479.0	0.000**
Visits to park/month	4.9	1.5	15 001.0	0.000**
		Consumption of foods from inside the sanctuary		
Household size	5.841	5.522	66 938.0	0.017*
Household education level	3.324	3.637	83 636.5	0.000***
Income/household size (US$)	$93.56	$114.61	81 872.0	0.014*
Land/household size (ha)	0.507	0.582	81 386.5	0.022*
Livestock (kg)	1172	1147	69 501.5	0.128
Rice shortage/household size(bins)	8.412	6.79	22 583.0	0.050*
Distance (km) to CWS	1739.536	1963.853	78 752.5	0.147
Visits to park/month	2.463	1.319	51 990.0	0.000**

* $p \leq 0.05$; ** $p \leq 0.0001$

Fuelwood

Almost all households utilize wood collected from the sanctuary for cooking fuel; fuelwood is the most commonly extracted forest product. Usually households (94%) collect fuelwood inside the sanctuary, including the core areas and buffer zone. The remaining households collect outside the sanctuary and buffer zone (3%) or purchase fuel (2%) (Figure 4.3D). Households primarily used branches or trees; only 5 households used charcoal. All used wood or charcoal to cook meals twice daily, and during the cold season fires are kept up throughout the day for heat. During the hot-dry season fires burn an average of 3.8 hours/day, compared to 5.7 hours in the rainy season and 10.3 hours/day in the cool-dry season.

DISCUSSION

Socioeconomics of Resource Use

My results parallel situations reported in research on many tropical dry forests throughout the world, which also show that rural people rely on these forests for their subsistence (Singh & Singh 1989; Appasamy 1993; Chopra 1993; Hedge et al. 1996; Murali 1996; Wickramasinghe et al. 1996; Abbot & Mace 1999), Research in dry forests also shows that those with fewer means such as land and income (Singh & Singh 1989; Appasamy 1993; Ganesan 1993; Hedge et al. 1996; Wickramasinghe et al. 1996; Abbot & Mace 1999), and lower education (Hedge et al. 1996) are more dependent on forest products than those with more means and education. Better educational and work opportunities along with improved use and alternatives to forest resources are needed for people to break the cycle of poverty concomitant with depletion of natural resources.

Poverty is rampant in Myanmar's rural populations (Van Schendel 1991; Mya Maung 1998; Myat Mon 2000; Booth 2003) and is the driving force behind substantial extraction of food, fuelwood, medicine and housing materials from CWS. Poverty, limited outside resources, education and work opportunities force rural populations to deplete their natural resources, which makes it even more difficult for them to overcome their poverty (Shaw 1989; Appasamy 1993; Ganesan et al. 1993; Hedge et al. 1996). These natural resources are essential to the survival of half the people at CWS—the half that cannot grow enough rice to feed their families and have to rely on sanctuary forests to supplement their crops.

During 15 years, from 1989 to 2004, there was a 62% increase in population of the area, including the six new villages that were relocated to area because of dam flooding (Myint Aung et al. 2004, Songer, unpublished data). As rural populations increase, pressures on the sanctuary can only be expected to increase. However, there is a clear need for further research to assess the direct impact of extraction on the sanctuary forest. This is a potential problem for many protected areas in Myanmar. A survey including two-thirds of the protected areas in Myanmar showed that 85% had evidence of forest product extraction, which the survey's developers ranked highest among the activities recognized as incompatible with protected area values (Rao et al. 2002).

Resource Use Patterns at Chatthin Wildlife Sanctuary

Previous studies on historical levels of wildlife and forest resources at CWS indicate that use patterns have been similar over a long period of time (Myint Aung et al. 2004). Major land conversion in the area began in the late 1800s with the British constructing the Mandalay-Mytkyina railroad. CWS was originally set aside as a fuel reserve for the railroad and was gazetted as a sanctuary only in 1941. Myint Aung et al. (2004) has described how a process of village establishment, agricultural conversion, logging, hunting and forest product extraction transformed a once large and intact tropical dry forest into a mosaic of degraded second growth.

Fuelwood extraction is the most pervasive use of the sanctuary forest, a pattern that has been shown in many dry forests (Singh & Singh 1989; Appasamy 1993; Ganesan 1993; Wickramasinghe et al. 1996). Fuelwood is the one forest product that is required on a daily basis for cooking and heating by all but a few CWS households. This finding supports the conclusion by Leimgruber et al. (2006) that fuelwood consumption is a major contributing factor to the dramatic declines in dry forest at the edge of Myanmar's central dry zone. Not surprisingly, fuelwood availability is declining at CWS. Over the past 5-10 years, local people have had to travel further into the forest and spend more time collecting enough wood to fill their carts than previously (Maung Ngwe & Taw Hla, personal communication)

Although a great threat to biodiversity in many tropical ecosystems (Redford 1992; Fa et al. 1995; Bodmer et al. 1997; Fa et al. 2000; Peres 2000; Wilkie 2005) hunting does not currently appear to be one of the high-frequency extractive activities going on in CWS. We found no evidence of hunting for organized wildlife trade. Animals usually are taken for household consumption or to sell in the local market. Bushmeat is not preferred over chicken, pork, or beef, as is common in some African countries. Local market surveys (Songer, unpublished data) indicate prices for wild-caught meat are roughly equal to those for livestock. However, studies on the sustainability of subsistence hunting in the area are still needed. Also, prices for wild-caught meat may have been lower when some of this wildlife was more abundant. Alternative means of protein production such as mushroom farming, rabbit farming, or small-scale fish farming may provide ways of offsetting demand for food from the forest and provide reliable food resources.

Grazing potentially has a negative impact on CWS that may continue to increase. More than 50% of households with livestock graze their animals inside the sanctuary; this is an activity that has been shown to negatively impact forest regeneration and biodiversity (Yonzon & Hunter 1991; Ganesan 1993; Das et al. 1996; Fox et al. 1996; Mishra & Rawat 1998; Cabin et al. 2000). Grazing is a subsistence strategy for low-income households that cannot afford land but have enough resources to purchase livestock. Livestock purchases require less capital than the costs of maintaining land, and animals can be grazed on common land or in the sanctuary. This conclusion is supported by the data showing that households with little land but proportionately more livestock relied more on sanctuary resources. Livestock grazing is probably linked to extraction of forest products within CWS. Herders move slowly through an area, are closely attuned to its natural features, and have their hands free for collecting. In developing alternative use strategies, increasing livestock does not appear to be a means of reducing forest use, unless the livestock is contained entirely outside the sanctuary.

Dynamics of Dry Forests

Research shows that globally tropical dry forests have the highest levels of decline compared to other tropical forest types (Janzen 1988; Wikramanayake et al. 2002; DeFries et al. 2005). Degradation of forest and diminishment of species used heavily by humans has been shown in many tropical dry forests (Appasamy 1993; Ganesan 1993; Murali et al. 1996). A country-wide assessment of high resolution Landsat imagery shows that dry deciduous forests were especially threatened by deforestation and that my study area is one of the top deforestation hotspots in the country (Leimgruber et al. 2006). Between 1990 and 2000 dry deciduous forests along the northern edge of the central dry zone declined by 7.0 %. Presumably, most of this rapid decline is due to fuelwood consumption and charcoal production (Leimgruber et al. 2006). Despite the absence of timber removal and other broad-scale conversions inside CWS, we can already see severe degradation and forest loss around and within the sanctuary boundaries via analysis of satellite imagery (Chapter 3).

My surveys demonstrate high resource use levels in the area, which may be contributing to the decline in forest cover inside CWS. The percentage of the local population relying on forest products demonstrates the tremendous productivity of an already degraded system (Chapter 3). Though I do not attempt to quantify depletion in this study, with the apparent high use levels there is the potential for resource depletion. Recent satellite imagery reveals that currently very little forest remains outside the sanctuary boundary (Chapter 3), suggesting that people will need to rely even more on the sanctuary forests in the future. Unchecked and continued use of CWS by the local population could result in resource depletion and the degradation of one of the largest remaining patches of tropical dry forest in Southeast Asia.

IMPLICATIONS FOR CONSERVATION

Effectiveness of Protection at Chatthin Wildlife Sanctuary

Current efforts to mitigate extraction impacts consist mainly of patrolling and enforcement of wildlife laws, aimed at stopping hunting and timber extraction. Evidence suggests that these activities have been effective in slowing deforestation inside the sanctuary boundaries (Chapter 3). Increased law enforcement is a necessary part of the solution and should remain an integral component of CWS management. Increasing sanctuary staff numbers, enforcing forest law, and monitoring the endangered Eld's deer began during the last decade. During this time the numbers of Eld's deer in the sanctuary reversed their decline and have steadily increased. However, there are many challenges for protected area staff in Myanmar, including limited training and education, lack of standardized protocols for law enforcement and poaching patrols, insufficient staff salaries, and lack of funding for patrols (Myint Aung 2006).

However, despite evidence of slowed deforestation inside CWS, traditional protection strategies are not likely to succeed over the long-term in the conservation of CWS. Ramping up protection and penalties for forest product extraction will most affect the poorest segment of the rural population. These households are already disadvantaged due to lack of access to resources, education, and professional opportunities. In addition it will likely be financially and logistically impossible due to a chronically very limited park operating budget and insufficient staff (Myint Aung et al. 2004; Myint Aung 2006). This is a problem facing nearly all protected areas in Myanmar (Rao et al. 2002; Myint Aung 2006), and is not likely to change in the near future. Less conventional methods may help conserve CWS in the long-term in a way that is fair and equitable to communities in the area.

Possible Mitigation Strategies

Without effective strategies for mitigating impact of forest product extraction, the future of CWS is potentially at risk. A key to success is to develop strategies that benefit both local people and the sanctuary. Since fuelwood is the most pervasive threat, developing alternative fuels and more effective means of using fuelwood could greatly reduce this threat to the sanctuary. Community forest plots, such as the ones in the dry forests surrounding Royal Chitwan National Park in Nepal (Nagendra 2002; Adhikari et al. 2004), can be developed and managed communally to help reduce demand for fuelwood from the sanctuary. Plots can be planted with preferred and fast-growing species and can be made accessible to people who are willing to use them in a sustainable manner.

Demand for fuelwood can also be reduced by the use of fuel-efficient stoves (Bazile 2002). Currently most households use open fires for cooking rather than stoves. However, energy-efficient, inexpensive, and easy-to-use stoves are produced in Myanmar and have been used successfully in other protected areas through the assistance of the Forest Resource Environment Development & Conservation Association (FREDA), a non-governmental organization composed of retired forestry officials interested in conservation. A majority of respondents (74%) said they would be willing to try to cook with stoves. Discussion with local stove owners suggests these stoves might cut fuelwood consumption by half, reducing the need for trees from the forest and decreasing the average workload for households (Khin Hla & Maung Soe, personal communication). Alternative fuel sources such as biogas may even be more effective for reducing the need for fuelwood and may be feasible in the future (Datta & Dutt 1981; Kalia 2000; Adeoti 2001; Nijaguna 2002).

Another key management strategy for CWS is the inclusion of local people as stakeholders in decision-making processes and in protection of the sanctuary. Involving people in these processes, for example, through outreach via workshops and discussion groups in local villages, can help people see the benefits they gain from the sanctuary and the need to keep it relatively intact to ensure future benefits (Fiallo & Jacobson 1995; Reddy & Chakravarty 1999; Allendorf et al., submitted). Illustrating the risks and benefits of different resource use strategies and their consequences may help to engage people in deciding how to maximize the available resources for their own benefit and in a way that allows for conserving the sanctuary. Some of these efforts have already started. During the past two years one of my in-country collaborators, the former park warden of CWS, has been holding workshops for village chairmen to talk about sanctuary issues and listen to their concerns. CWS already has an environmental education team and a visitor's center. These activities, along with the warden's efforts to foster good relationships with villages, puts CWS in a good position to begin community forestry and other impact mitigation programs. However, these activities are dependent on outside assistance, such as from non-governmental organizations, since protected area budgets in Myanmar do not provide for such endeavors.

The Greater Context

Though local socioeconomic factors drive much of the resource extraction at CWS, national level actions also have an impact on CWS and surrounding communities. Thapanseik Dam, constructed 20 km to the south of CWS, resulted in six villages being relocated very near the sanctuary boundary. People lost their homes and crops but received minimal or no compensation and had to rely primarily on sanctuary resources to earn their livelihoods while planting new land. National agriculture and land use policies often omit consideration of protected areas and how they may be impacted. For example, in 2000, Myanmar's State Peace and Development Council decided CWS would be a good area to develop for agriculture to meet increasing needs for food (Myint Aung et al. 2004). This was stopped upon the objection of the Ministry of Forestry, but it illustrates the problems that can arise when ministries are working separately and with differing goals. Improved and coordinated land use planning policies could help alleviate some of the pressure on CWS and other protected areas and should be integrated with this work.

During the past decade the CWS warden and staff have made remarkable improvements to the management and protection of the sanctuary by increasing the number of staff working inside the sanctuary, implementing regular patrol teams to protect against poaching, and beginning education and outreach programs in nearby villages. Research support and training by Smithsonian scientists have increased capacity of the staff through training opportunities, enhanced staff morale, and improved staff welfare (Myint Aung et al. 2004; Wemmer et al. 2004). There is also evidence that staff interactions with people have had positive affects on attitudes (Allendorf et al., submitted) suggesting potential for improving people-park relationships through workshops, education programs, and staff visits to the villages. Though changes are needed on many fronts, these successes over the last decade give reason for optimism. Through continued and expanded efforts it is still possible to protect and even enhance this important tropical dry forest remnant in ways that are beneficial to the people who are dependent on the forest.

Chapter 5: Conclusion

Linking Multi-Scale Studies

Though the various processes affecting dry forests are occurring at different scales, they are all linked and need to be considered jointly for the development of effective strategies for protecting remaining dry deciduous forests. My research clearly demonstrates that dry deciduous forests in Myanmar are seriously threatened by growing human populations and rapidly expanding agriculture, and are poorly protected from these threats. Only 24,000 km^2 of this ecosystem remains, only about 960 km^2 (4%) is protected, and all of it is highly fragmented, with only 27 fragments larger than 100 km^2. The land use change patterns emerging from my multi-temporal and multi-scaled studies illustrate how broad-scale agricultural conversion, shifting cultivation, and hydroelectric development have impacted remaining dry deciduous forests. Many of these changes have been happening at national scales where governmental policies on forestry, agriculture and energy are major factors. However, local level assessments show that, in addition to national policies, rural human populations continue to have a key role in dry deciduous forest ecosystems. These combined forces of deforestation and land use change are difficult to stem, even in legally protected areas such as Chatthin Wildlife Sanctuary (CWS). As forests dwindle, the need to protect their value to the subsistence of local people may become increasingly apparent. Dry deciduous forests provide essential resources to a large proportion of the people living throughout the CWS landscape. Nearly all households use products from the sanctuary. The poorer and less educated people are the ones most dependent on these resources.

My analyses of temporal and spatial deforestation dynamics at CWS represent only a snapshot in history. Botanists and foresters of 19th century colonial Burma tell us that this zone was mostly forested less than 200 years ago (Kurz 1877, Stamp 1925). As human population expanded and the concurrent need for more agricultural land increased, dry deciduous forests gradually changed and began to disappear. In some locations, the colonial authorities may have accelerated this process via recolonization programs, settling different ethnic groups in previously forested areas (Bryant 1997). In other areas, forest conservators and local officials may have stemmed shifting cultivation pressures in order to preserve forests for later cutting by the teak industry or, as in the case of CWS, as fuel reserves for the newly established railroad (Myint Aung 2006). It is likely that forested areas across the central dry zone were at first converted as a part of long-established traditional shifting agricultural practices, which would have allowed for secondary succession, but gradually were transitioned into permanent agriculture lands, eliminating any further forest succession. Patterns in the marginal and hilly areas surrounding CWS may still follow that conversion route. However, the rapid conversion seen in the direct proximity of CWS is likely a deforestation phenomenon characteristic of the late 20th and 21st century, and can be traced back to recent misguided agriculture and energy policies.

Today, the central dry zone has been mostly converted to permanent agriculture, with the exception of a few isolated protected areas. Observing spatial and temporal patterns of change in the transitional frontier that is moving ever closer and into the northern edge of the central dry zone gives us insight into the past processes that have made the landscape what it is today.

My case study of land cover change at CWS is also illustrative of a relatively new environmental threat that is rapidly increasing in force across Myanmar. Hydroelectric projects have been increasingly developed and implemented over the past 10 to 15 years (Hirsch 1995, cited by Eberhardt 2003), since it has become profitable to Myanmar to allow nearby countries to build dams within Myanmar's borders and export the energy produced. My research shows that the impact from these dam developments cascades through the landscape, radiating out from the initially impacted watersheds. The direct consequences of hydroelectric developments, as seen with Thapanseik Dam near CWS, include the clearing of forests likely to flood, the uprooting of 52 villages and thousands of households, and the permanent flooding of homes and croplands. The after-effects in more widely surrounding areas include conversion of new areas for housing and agriculture, increased hardship and dependence on natural resources, more encroachment into protected forests (Myint Aung et al. 2004). These effects can be multiplied by the number of dams that are already built or are in the process of being constructed around the country. Currently a dam on the Chindwin and Uru Rivers is slated for completion in 2007 and is predicted to flood at least half of a protected area, Htamanthi Wildlife Sanctuary (HWS). HWS supports elephants and many other species, and until the past two decades provided habitat for the endangered rhinoceros (Rabinowitz et al. 1995).

Analysis of the demand for forest products at a finer scale provides a better understanding of local drivers of change that are difficult to detect via satellite imagery at a 250 m (MODIS) resolution, or even at a 30 m (Landsat) resolution. Understanding these local drivers, along with understanding landscape-level changes are key for developing more comprehensive strategies for conserving dry deciduous forests. My interview survey outlines a picture of the pervasiveness of local people's dependence on forest products and the high level of ongoing extraction pressures. On the ground, the consequences of these extraction pressures can actually be seen along the boundaries of CWS. However, it is difficult to make this type of assessment without detailed knowledge of the sanctuary, interviews with the warden and local people, and experience in the forest. Based on this knowledge I have ascertained that much of the degradation and forest loss inside the sanctuary boundaries is not a result of agricultural conversion, but rather results from the adverse impacts of forest product use. Such impact is evidenced in 85% of the protected areas surveyed around the country (Rao et al. 2002). However, extraction for local consumption clearly is not limited to protected area forests, but occurs in forests around the country and affects the remaining unprotected dry forests. While traditional remote sensing may not allow us to distinguish extraction-caused degradation from agricultural conversion, by employing a multi-scale approach which includes a local-level study of the people of CWS, I gain a crucial insight into other important drivers of land use change such as this extractive pressure, occurring at a much finer scale than the more easily detected agricultural activities.

Lessons for Dry Forest Conservation

The results from my dissertation research are consistent with the patterns that emerge from other studies and provide a bleak view of the current status of dry forests around the world. Others have shown how dry forests are falling between the cracks in research, conservation, and even in management (Janzen 1988, Sanchez-Azofeifa et al. 2005). In addition to being one of the most heavily used forest types, dry forests are complex ecosystems that can be difficult to delineate, monitor, and manage (Bunyavejchewin 1982; Murphy & Lugo 1986; Janzen 1988; Bullock et al. 1995; Maass 1995). My results and research experiences provide some insights into the direction research and related conservation of dry forests might take. A set of simple priorities for organized research on dry forests of Myanmar, and possibly of other countries, may be distilled from my research:

1) Develop countrywide dry forest databases and maps to delineate more accurately current and past extent of dry forests.
2) Based on these maps, identify priority areas for conservation and protection of dry forests at the country level.
3) Conduct case studies at local levels to determine land use changes that are affecting dry forests.
4) Conduct socioeconomic and attitude surveys at local scales to determine the value and uses of dry forests to local communities.
5) Based on case studies, develop alternative use models and strategies. Implement and test these strategies on the ground.

For Myanmar and the CWS region, my dissertation research and analysis have realized several of these research priority steps, while others, most particularly the development of alternative use models and strategies, largely remain to be addressed in future endeavors. A multi-scale and multi-temporal approach allows investigation of factors and drivers that would be missed with a single scale or single snapshot in time. Each component, particularly in correlation and contrast with each other, provides valuable insights into issues critical to tropical dry forest conservation.

Mapping Dry Forests and Regional Planning

Accurate maps and databases on dry forests are essential for the conservation of these highly endangered and extremely valuable ecosystems. Accurate maps could provide presently scarce information on current, and potentially on past, extent of dry forests. In combination with land cover change data, these databases may shed light on the rate and pattern of forest loss and on the factors driving these losses. These maps also can be used for long-term planning, by helping planners and managers identify areas that should receive special protection and management.

Though global land cover data are useful for many purposes, such as input for global biogeochemical and climate models, my work shows assessments of conservation status for dry forests cannot be based on these maps. My accuracy assessments in Chapter 2 demonstrate that regional and global land cover data do not provide accurate delineations of dry deciduous forests in Myanmar; and most likely not in other places either. These maps have fairly low accuracies for dry forest. Even more important, they demonstrate very little agreement on locations of remaining dry land and dry deciduous forest in Myanmar. This is not surprising: it simply highlights the very different focus, scale and intended uses of global and regional land cover data. Dry forests cover a small area in total, and individually they are rare, fragmented and dispersed. As a consequence they are hard to map; by the same token, inaccuracies in delineating these land cover types may have little effect on the overall accuracy of these global maps. However, for effective conservation strategies regarding tropical dry forests, it is essential to have reliable regional or countrywide maps verified with ground knowledge as a basis for planning, rather than relying on existing global land cover maps.

Utility of Remote Sensing

Mapping open canopy dry forests and dry deciduous forests using satellite remote sensing poses serious challenges. Existing mixture models, such as the Vegetation Continuous Fields (VCF) data, may saturate at the lower end of observed canopy densities of dry forests, resulting in an underestimation of these forest types. The models also require extensive ground data on canopy densities across the entire study area. These data are difficult to come by especially in a geographically and politically isolated country such as Myanmar. Mixture model techniques are fairly complex, and may be difficult for local forest and agricultural officers to implement.

Exacerbating the problems regarding delineating dry forests are several particular characteristics of this land cover type. These characteristics include their relative uncommonness, fragmented and dispersed spatial distribution, small average fragment size, and seasonal phenology. Additionally, the natural and human-caused fires affecting these forests at times make their spectral signatures confusingly similar to degraded forest types.

Using freely available MODIS NDVI composites in combination with simple supervised classification techniques, I produced a dry deciduous forest map for Upper Myanmar that may be the most accurate that is currently available for the area.

Accuracies for my map were considerably higher than accuracies achieved by any of the global and regional land cover data sets I tested. The comparative strengths of my technique and source data over the ones used by global and regional land cover maps are: a higher spatial resolution (250 m), focused on delineating only two land cover classes (dry forest vs. other), detailed knowledge of the ground through many visits to the country's dry zone and other areas, and a large number of seasonal ASTER and Landsat images for validation. Most of these techniques can be applied to other countries with substantial dry forest cover. All of these differences are likely to provide better accuracy for mapping a land cover type with spectral and spatial attributes similar to dry forests.

Satellite imagery is also valuable for evaluating the effectiveness of protected areas; at least in terms of preserving forest cover (Zheng et al. 1997, Curran et al. 2004, Linkie et al. 2004, Maselli et al. 2004, Trigg 2006). A time series of imagery of an area can be particularly helpful in understanding the spatial and temporal dynamics of land cover change in the area. Combined with environmental history data it is possible to consider how various policies, conditions, or particular events may have impacted the landscape.

Remote sensing based on satellite imagery will also prove a valuable tool to continuously assess the effectiveness of protected areas for habitat and ecosystem conservation. This type of monitoring can reveal any significant changes in land use or land cover over time, and can be done in an objective manner. However, remote sensing monitoring needs to be integrated with other performance measures, because biodiversity is not only a function of canopy intactness. Poaching and extraction of resources other than trees usually cannot be measured or quantified via remote sensing data sources.

Losing Dry Forests

It is unclear how much of the dry forest ecosystem has already been lost. Dry forests have not been systematically inventoried or even delineated at regional, national or international levels. It is likely that most of the dry forests that existed in Myanmar only 200 years ago have already disappeared. The currently existing forest conversion pressures are not likely to decrease, but rather will continue to multiply as rural populations and consumptive demands increase. The dry deciduous forests of Myanmar, by nature, produce a vast number of commodities and resources for local populations. Their very usefulness is a major underlying factor leading to their decline. As forest decreases, and rural populations continue to burgeon, the demands for products increase.

Ultimately the loss of dry forests in Myanmar will have more negative impact on the poorest segment of the rural populations—the group of people that have too little land upon which to graze their cattle or produce enough rice. The long-term effects will extend well beyond this group. Agricultural landscapes in Myanmar's once forested central dry zone are already experiencing the consequences of forest loss: increased erosion, loss of soil fertility, and increased drought. Though baseline data for systematic studies of the consequences of dry forest deforestation are currently not available from Myanmar, the patterns are already familiar, having been observed elsewhere.

Effectiveness of a Dry Forest Protected Area

My analysis of temporal and spatial deforestation dynamics at CWS demonstrates the urgency of dry forest conservation in Myanmar. The example of CWS, a relatively small protected area surrounded by a landscape in which most forest has been cleared, shows that protected areas can be effective in stemming degradation. This seems to have been true even during periods when the park lacked staff and resources in the 1970s and 1980s and probably was effectively only a paper park. If even paper parks slow habitat loss, then this is a forceful argument in favor of establishing new protected areas as one of the strategies for conservation of dry deciduous forests.

To date, however, few of Myanmar's protected areas encompass dry or dry deciduous forests. The time for creating more protected areas to preserve this ecosystem is rapidly running out, as the last remaining patches are already being affected by land use changes. In addition to creating new protected areas, improving the infrastructure and resources at CWS and some of the other areas would also benefit dry forest conservation.

Use and Value of Dry Forests

A large number of people in the countryside surrounding CWS, as elsewhere throughout the world, depend on dry and dry deciduous forests for their livelihood. Fuelwood consumption for cooking and charcoal production is probably the most serious threat to the sanctuary ecosystem. These driving factors have long been identified as the culprit in many dry forests around the world (Singh & Singh 1989; Appasamy 1993; Ganesan 1993; Murali et al. 1996; Wickramasinghe et al. 1996). In Myanmar, a country rich in oil and gas resources, it is striking that alternative strategies for fuel consumption have not been pursued aggressively. Even basic strategies of using bio-fuels or growing fuel for everyday needs have not been tried. There is also considerable pressure for converting wood to charcoal, the preferred fuel in urban areas. This demand is causing degradation and forest loss in many areas of the country (Leimgruber et al. 2006).

Simple and inexpensive clay stoves, referred to locally as the "one-stick stove", are easily available in local markets. Discussions with people using these stoves and preliminary results of a controlled study of fuelwood use in homes with stoves and homes without stoves suggests that they could potentially cut fuelwood use in half in most households (Songer, unpublished data). Three out of four people interviewed during the survey said that they would be willing to use stoves if they were available. However it seems habit, and sometimes cost inhibits people from acquiring and using the stoves. One simple way to cut fuelwood demand would be to encourage the use of stoves and distribute them for free. Once people discover the work-saving benefits of the stove they may be willing to invest their own money in the future to purchase replacements. This type of innovation is an example of a potential win-win situation for people and forests.

Next Steps

My research shows that a simple process for analysis of MODIS NDVI data can produce accurate delineations of dry deciduous forests in Myanmar. These mapping efforts should be expanded and possibly further simplified. Potentially, simple unsupervised and cluster-busting techniques may yield similar results to what I accomplished, if they are focused on classifying only dry deciduous forests. Such techniques can be used for mapping at national universities, thus allowing for in-country mapping of a nation's dry forest ecosystem resource. Ultimately, it is the ministries, resource agencies, environmental organizations, and local people that need to be in charge of efforts to inventory, plan, manage and conserve dry forests. One conservation priority in Myanmar should be training workshops to build such mapping capacity.

Once improved countrywide maps of dry deciduous forests are available, they can be used to identify priority areas. Finer scale studies on land use/land cover changes for priority dry forest areas across Myanmar would be the next step, and would help determine which national policies and practices have the greatest effect on these ecosystems. The Geocover data set provides multitemporal Landsat images for 1990s and 2000, so imagery is already available for this type of assessment (Tucker et al. 2004).

This information is urgently needed to convince policy makers of the dire situation these dry forest ecosystems face. However, conducting such an assessment is also useful because it can provide detailed information to national policy makers on the consequences of energy and agricultural policies for natural resources such as dry forests. The maps and data can also be used to test different scenarios for land use changes, for example, to determine what will happen if an adjacent watershed is used for a hydroelectric development. With these maps, in combination with detailed data on local use, it may become possible to calculate the economic losses resulting from such developments.

Village survey assessments provide the baseline data for management planning, including means for mitigating human impacts on the forest, and also aid in providing directions for new research. From my present research results, we know that the people most dependent on the CWS-area forests are those already at a disadvantage as a result of poverty and limited education. Ideally we can develop feasible alternative use strategies that could benefit people in ways that reduce forest impact. Around CWS, aside from fuelwood, providing food is the most common purpose of regularly and seasonally collected forest products. Alternative protein sources, for example, small-scale mushroom or rabbit farming, could provide reliable supplemental food sources that have little impact on the forest. CWS staff have developed a method for raising fish that does not require a lot of input materials or space. This type of innovation could provide a regular source of protein or even some income for families.

Community forestry may be a way to provide fuelwood to people while improving forest cover in areas buffering the sanctuary. Community forestry and other projects can only be advanced through collaborative efforts with people of the area. They are unlikely to succeed in the long-term unless local people are a part of the design, planning and implementation. Success for such operations also often depends on a few dedicated leaders in the communities. Community forestry plots have been successful in similar forest ecosystems found in Nepal (Gautam et al. 2002, Nagendra 2002; Adhikari et al. 2004). An existing government program already encourages the development of such plots (Eberhardt 2003). Areas just outside the sanctuary's boundary could be set up as common forest plots and planted with fast-growing species. Villagers could have access to the area with an agreement to use it in a way that would not diminish its capacity.

Clearly, threats to dry forests of Upper Myanmar are occurring on multiple scales. To counteract generations of degradation and deforestation, a comprehensive conservation strategy will need to move on many fronts. Starting from broad scale assessments of remaining forests and using these maps to prioritize and plan for land use, managers and planners can move on to working within the protected area systems to expand and improve protection, and to exploring innovative ways to help meet the needs of humans while reducing impacts to the forest. Any one of these tactics implemented alone will not be enough to stop the long-term decline of tropical dry forests.

Appendices

Appendix A. Income and demographic characteristics for villages at Chatthin Wildlife Sanctuary.

Village	Population in 2004	Mean household size	Mean household income (US$)	Mean household education	Mean # of visits/ month	Mean land/ household size (ha)
Kyein	468	5.21	497.71	2.79	6.21	0.47
Satthachaung	450	5.57	558.65	2.98	2.36	0.44
Singaung	531	5.57	681.41	3.03	1.14	0.60
Chatthin	3820	5.11	286.77	4.08	6.50	0.02
Thitseingon	694	5.21	254.89	3.34	1.54	0.46
Leyinte	740	5.11	483.27	3.30	1.18	0.64
Kangyi	970	6.18	853.01	4.81	2.32	0.81
Ywathit	575	5.00	190.08	3.04	0.75	0.14
Lekokpin	515	6.29	692.48	3.29	1.36	0.59
Taunggya	1100	5.68	443.16	3.34	1.14	0.45
Paytapin	1210	5.70	489.28	3.36	0.48	0.15
Aungchantha	320	4.79	327.63	2.94	0.96	0.44
Thigon	970	5.68	434.29	3.49	2.32	0.32
In-ngoto	1164	6.11	582.29	4.05	3.25	0.62
Tamagon	385	6.14	488.47	3.52	4.57	0.47
Panmaye	570	5.52	413.97	3.27	2.03	0.44
Alegon	1003	5.96	878.95	3.83	0.75	0.89
Paunkseingon	414	5.89	504.72	3.86	0.44	0.55
Lwingyi	387	6.28	697.10	4.04	0.34	0.70
Sinma	830	5.29	565.11	2.94	1.43	0.41
Gwetauktaw	750	5.79	373.87	3.43	0.86	0.31
Chatgon	1450	6.61	1440.50	4.25	1.11	0.91
Hlepwe	422	5.96	622.26	4.13	0.23	0.66
Zigana	1203	5.61	541.82	4.03	0.64	0.67
Hnawgon	1500	5.86	704.47	3.37	0.75	0.55
Nyaunggon	746	5.71	775.58	3.30	1.14	0.58
Palutha	150	5.54	572.78	2.70	1.61	0.62
Magyigon	538	5.14	819.17	2.41	1.43	0.53

Appendix B. Questionnaire used for village surveys.

Village survey form

Interview number: _________ Interviewer name:________________

Village: ____

Time: ______________________ Date: ______________________

Background information:

Male or female: ______________ Forest expert: yes[ ] or no [ ]

Age: _________________ Occupation: ______________________

Education (Standard): _______________

Land owned by household (acres): _______________

Number of people in family: ____________

Agriculture Questions

1. How many acres of rice does your household plant each year?
2. How much rice does your household harvest each year?
3. Last year, did you have enough rice for your family?

   [ ] yes [ ] no
4. If no, how much did you have to buy?
5. What do you do with your surplus rice or other crops?
6. If you sell them, where do you sell them?
7. What percentage of your crops is surplus?
8. Is fertilizer used on your crops? What type?
9. Is irrigation used for your crops? What method?
10. What animals do you keep as livestock?
11. How many cows and buffalo do you have?
12. How many dogs does your household have?
13. What do you feed your animals?
14. Where do you get food for the animals?

15. Where do you graze the animals?

    [ ] paddy field

    [ ] buffer zone

    [ ] core areas

16. If you buy food for the animals, where do you buy it?
17. Please tell us what foods you ate yesterday, and indicate where these foods came from with a check mark.

Type of Food	Family grew crop	Livestock	Collected/hunted from forest	Purchased at market
Rice				

18. How many times do people in your household cook each day?
19. How much wood do you require for cooking a meal?
20. How long do you burn fires each day in the dry season?
21. How long do you burn fires each day in the rainy season?
22. How long do you burn fires each day in the cold season?
23. If you could have a stove that did not require a lot of fuelwood, would you like to use it?

Forest Product Questions

1. Who in your village is an expert in forest knowledge such as plants, trees, animals?
2. How many times each month do you go to the forest?
3. Besides agriculture, what other ways do you get food for your family?
4. How many people in your household can catch the animals listed below?

Animal	How many people can catch them?	Where do you find them?	How do you catch them?
Lizards			
Frogs			
Snakes			
Rats			
Rabbits			
Fish			
Jungle cat			
Pangolin			
Armadillo			
Turtles			
Birds			
Muntjac			
Thamin			

5. What types of products do you or members of your household gather from the forest? If there is a product that is not listed it can be added in the blank sections.

>>**Importance** is ranked with a number 1 through 5. A score of 1 means the product is not necessary, a score of 5 means the product is essential for the family to survive. The numbers in between are different degrees between these extremes. <<

Forest Product	Use of product	Where collected	Importance (1-5)
Honey			
Bee Larvae			
Thatch			
Mushrooms			
Truffles			
Bamboo Shoots			
Bamboo			
Pwe nyet			
Lacquer			
Deer Antlers			
Leaves for packing			
Eugenia leaves			
Flowers			
Payit			
Resin			
Scented oil			
Vegetables **			
Fruit **			

** Interviewers please write specific names of fruits and vegetables on the back of this page.**

6. What plants do you use for medicine?

7. Where do you get these plants?

8. How often do you use plants for medicine?

9. In your village, who spends much time collecting products from the forest?

10. What products do you use for fuelwood? (trees, branches, charcoal, other)

11. Where do you get fuelwood?

    [ ] buffer zone

    [ ] core areas

    [ ] outside sanctuary

12. How many cartloads do you use each month?

13. Do you buy fuelwood?

14. Where do you buy it?

15. How much do you pay?

16. Where do you get your wood for house poles?

17. How many housepoles do you collect each year?

Household Questions

1. Were you born in this village?

2. How many years has your household lived in this village?

3. In your household, who makes decisions about how to spend money?

4. If you have extra money, what do you like to buy?

5. Where do you get money to buy products in the market?

6. What items in your house are most valuable?

Item	Value in kyats

7. Do any members of your family live outside your village? How many?

8. Where do they live?

9. What occupation do they have?

10. What is the most important need of your household?

11. What job opportunities would help you or your household?

Family member (#)	Education Level	Where received education	Occupation (may be more than 1) *	Amount paid	Time spent (months)

12. What educational opportunities would help you or members of your household?

13. Are there any programs or projects that might help your village?

14. Have there been changes in your household that are caused by building the dam?

Appendix C. Food and household products, their purpose, scientific names, number of respondents who mentioned it, and the mean importance rank (5 = essential for survival, 1 = not necessary).

Item listed	Primary purpose	Scientific name	No. of times mentioned	Average rank of importance
Bamboo	food, many household uses	Various	23	1.7
Bamboo shoots	food	Various	563	2.0
Bee larvae	food		13	1.2
Bitter gourd	food		10	1.2
Chili	food	Various		
Chut cho	food		15	1.0
Coecinia fruit	food			
Coecinia leaves			4	1.0
Deer Antlers			1	1.0
Eugenia leaves	food, religious	*Eugenia kurzii*	65	1.4
Fish	food			
Flowers	religious		17	1.9
Frogs	food			
Fruits	food		264	1.6
Gyo-che	food -young leaves	*Tamarix dioica Roxb.*	2	1.0
Honey	food		15	1.2
Indian night shade (kyaungsha)	food	*Oroxylum indicum Vent.Syn.*	4	1.3
Indian trumpet fruit	food	*Oroxylum indicum Vent.Syn.*	2	1.0
Kanyut	food		2	1.0
Kapyin			5	1.0
Kayout			1	1.0
Kazawthi	food		2	1.5
Kha chou	food -young leaves	*Smilax macrophylla Roxb.*	2	1.0
Kinpalin	food - leaves	*Amphidesma diandrum*	53	1.1
Kok-ko	young leaves	*Albizzia lebbeck*	13	1.1
Kyaung shar flower	food			
Kyetmauk leaves	food			
Kyetet (leaves)	food		1	1.0
Lobster oil	food			
Mollusk	food			

Appendix C. cont'd.

Item listed	Primary purpose	Scientific name	No. of times mentioned	Average rank of importance
Indian trumpet fruit	food	*Oroxylum indicum Vent.Syn.*	2	1.0
Monoto		*Oxalis corniculata*	1	1.0
Mushrooms	food		566	1.8
Pwe-nyet	boat sealer	*Dipterocarpus tuberculatus*	1	3.0
Resin	waterproofing baskets	*Melanorrhoea usitata Wall*	1	3.0
Roselle	food - leaves		1	1.0
Sauce				
Su-ngut	young leaves	*Asparagus officinalis*	4	1.0
Tamarind	food	*Tamarindus indica*	2	1.0
Thabyet	food		1	1.0
Thatch	roofing material	*Imperata cylindrica L*	443	2.1
Thin-wun leaves	food		1	1.0
Thorny creeper			1	2.0
Truffles	food		487	1.8
Vegetables	food		286	1.7
Water greens	food		17	1.2
Yinpya	food - young leaves	*Dichroa febrifuga*	1	1.0

Appendix D. Medicinal plants, their common name, treatment, and scientific name.

Plants	Treatment for	Scientific Name
Ba-hone-myit	wounds	*Desmodium pulchella*
Besat	wounds	
Bon-ma-ya-zar	sore throat	*Rauvolfia serpentina*
Dan-tha-khwa	indigestion	
Emperor plant	gout	
Gamon shwe-thange	swelling	
Gonga	indigestion	
htanaun bark	constipation	
Hseik-phu	wounds	
Htauk-shar-myit		
Hti-ka-yon	bladder infection	*Mimosa pudica*
Hti-ke-tali-teu	itching	
In-di-paw-guy		
In-di-say-ni	sores	*Ochna fruticulosa*
Ingyin bark		*Shorea siamensis*
Jar-mani	bleeding (control)	
Kain-na-yar		*Dendrobium longicomu*
Kain-na-yi	sores	*Dendrobium eriaeflorum*
Khat-tar	sore throat	*Crinum amoenum*
Kha-paung-ye-gi	gonorrhea	*Celtis cinnamomea*
Khin-say	diarrhea	
Kyar-san-nwe		*Rosa gigantea*
Le-gar-zi-byu		*Euphorbiaceae*
Lauk-the	asthma	
Le-gar-zi-byu	jaundice	
Let- htok		*Holarrhend antidysenterica*
Lin-pyar		
Mae-za-li	indigestion	*Cassia siamea Lan*
Min-say	bladder infection	*Sauropus compressus*
Myethname		*Eragrostis barbulata*
Myin-gaung-na-yaung		*Celastrus paniculatus*
Nga-pay-shin	blood disorders	
Nga-saing-shin	gout	
Ngu sat	swelling (purgative)	*Cassia renigera*
Ngu-shwe	jaundice	*Cassia fistula*
Nwe-cho	swelling	*Albizia myriophylla Benth*
Nwe-nyo		*Thunbergia penduia*
O-bo-myit		*Glycosmis pentaphylla*
Pan-mauk-khone		*Vitis discolor*

Appendix D. cont'd.

Plants	Treatment for	Scientific Name
Pa-tat-sa		*Kaempferia candida*
Pauk-pwint		*Butea monosperma*
Phan kha	indigestion	*Terminalia chebula*
Pha-hon		*Desmodium pulchellum*
Pan-mauk-khone	bladder infection	
Phwa bat myit	gonorrhea	
Phwar-bet	malaria	
Pin-sein-net	children's illness	
Satalon-u	gonorrhea, gout	
Shin-ma-tat	(tonic)	*Asparagus acerosus*
Si-mi-tauk		*Stemona tuberosa*
Sin-don-ma-nwe	livestock	*Tinospora cordifolia*
Sin-khat-cho-u		*Smilax glabra*
Sin-tha-pho	asthma, gout	
Ta-ba-ki or ta-bat-kyi	arthritis	*Miliusa velutina*
Taung-kyar	bladder infection	*Staphania vewsa*
Taw-khat-tar-U	broken bones	*Crinum amoenum*
Thanmanaing-kyauk-ma-naing	bladder infection	*Indigofera linifolia*
Tha-nat-kha	skin (protection)	*Hesperethusa crenulata*
That-ke-kyi myit		
That-yin-gyi-myit	joint pain	*Croton roxburghianum*
Thik-wa	swelling	*Bambusa burmanica*
Thit-swe-le bark	gonorrhea	*Schrebera swietenioides*
Trumpet bark	(antidote)	
Wun-u	livestock, wounds, jaundice	*Pueraria candollei Wall.*
Vail root	gout	
Yin-bya	menstrual (purgative)	*Dichroa febrifuga*
Yon		*Anogeissus acuminata*
Zi-byu	vitamin C deficiency	*Emblica officinalis*

References

Abbot, J. I. O., and R. Mace. 1999. Managing protected woodlands: fuelwood collection and law enforcement in Lake Malawi National Park. Conservation Biology **13:**418-421.

Achard, F., H. D. Eva, H-J. Stibig, P. Mayaux, J. Gallego, T. Richards, and J-P. Malingreau. 2002. Determination of deforestation rates of the world's humid tropical forests. Science **297:**999-1002

Adeoti, O., T. D. Adegboyega, and T. A. Ayelegun. 2001. An assessment of Nigeria biogas potential from agricultural wastes. Energy Sources **23:**63-68.

Adhikari, M., S. Nagata, and M. Adhikari. 2004. Rural household and forest: an evaluation of household's dependency on community forest in Nepal. Journal of Forest Research **9:**33-44.

Allendorf, T. D., Khaing Khaing Swe, Thida Oo, Ye Htut, Myint Aung, L. A. Hayek, P. Leimgruber, and C. Wemmer. Community attitudes toward three protected areas in Upper Myanmar (Burma). (Submitted to Environmental Conservation).

Appasamy, P. P. 1993. Role of non-timber forest products in a subsistence economy: the case of a joint forestry project in India. Economic Botany **47:**258-267.

Arendt, A. A., K. A. Echelmeyer, W. D. Harrison, C. S. Lingle, and V. B. Valentine. 2002. Rapid wastage of Alaska glaciers and their contribution to rising sea level. Science **297:**382-386.

Bazile, D. 2002. Improved stoves as a means of poverty alleviation. Boiling Point **48:**20-22.

Baraldi, A. and L. Bruzzone. 2005. Quality assessment of classification and cluster maps without ground truth knowledge. IEE Transactions on Geoscience and Remote Sensing **43:**857-873.

Bartholome, E. and A. S. Belward. 2005. GLC2000: a new approach to global land cover mapping from Earth observation data. Journal of Remote Sensing **26:**1959-1977.

Belward, A. S., J. E. Estes, and K. D. Kline. 1999. The IGBP-DIS global 1km land cover data set DISCover: a project overview. Photogrammetric Engineering and Remote Sensing **65:**1013-1020.

Bodmer, R. E., J. F. Eisenberg, and K. H. Redford. 1997. Hunting and the likelihood of extinction of Amazonian mammals. Conservation Biology **11:**460-466.

Booth, A. 2003. The Burma development disaster in comparative historical perspective. SOAS Bulletin of Burma Research **1:**1-23.

Botteron, C.A. 2001. India's "Project Tiger" reserves: the interplay between ecological knowledge and the human dimensions of policymaking for protected habitats. Pages 137-162 in V. H. Dale, and R. A. Haeuber, editors. Applying ecological principles to land management. Springer Science and Business Media, Berlin, Germany.

Brashares, J. S., P. Arcese, M. K. Sam, P. B. Coppolillo, A. R. E. Sinclair, and A. Balmford. 2004. Bushmeat hunting, wildlife declines, and fish supply in West Africa. Science **306:**1180-1183.

Brook, B. W., N. S. Sodhi, and P. K. L. Ng. 2003. Catastrophic extinctions follow deforestation in Singapore. Nature **424:**420-423.

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology **16:**909-923.

Bryant, R. L. 1997. The Political Ecology of Forestry in Burma, 1824–1994. C. Hurst & Co., London, United Kingdom.

Bullock, S. H., H. A. Mooney, and E. Medina. 1995. Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

Bruijnzeel, L. A. 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? Agriculture Ecosystems and Environment **104:**185-228.

Bruner, A. G., R. E. Gullison, R. E. Rice, and G. A. B. da Fonseca. 2001. Effectiveness of parks in protecting tropical biodiversity. Science **291:**125-127.

Brunner, J., K. Talbot, and C. Elkin. 1998. Logging Burma's frontier forests: Resources and the regime. World Resources Institute Press, Washington D.C.

Bunyavejchewin, S. C. 1982. Canopy structure of the dry dipterocarp forest of Thailand. University of Washington, Seattle, Washington.

Cabin, R. J., S. G. Weller, D. H. Lorence, T. W. Flynn, A. K. Sakai, D. Sandzuist, and L. J. Hadway. 2000. Effects of long-term ungulate exclusion and recent alien species control on the preservation and restoration of a Hawaiian tropical dry forest. Conservation Biology **14:**439-453.

Ceballos, F.1995. Vertebrate diversity, ecology, and conservation in neotropical dry forests. Pages 195-220 in S. H. Bullock, H. A. Mooney, and E. Medina, editors.

Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

Chauvaud, S., C. Bouchon, and R. Maniere. 1998. Remote sensing techniques adapted to high resolution mapping of tropical coastal marine ecosystems (coral reefs, seagrass beds and mangrove). Journal of Remote Sensing **19:**3625-3639.

Chopra, K. 1993. The value of non-timber forest products: an estimation for tropical deciduous forests in India. Economic Botany **47:**251-257.

Cihlar, J. 2003. Thematic Mapper TM based accuracy assessment of a land cover product for Canada derived from SPOT VEGETATION (VGT) data. Canadian Journal of Remote Sensing **29:**154-170.

Clark, P. U., N. G. Pisias, T. F. Stocker, and A. J. Weavers. 2002. Thermohaline circulation in abrupt climate change. Nature **415:**863-869.

Coppin, P. R., and M. E. Bauer. 1996. Digital change detection in forest ecosystems with remote sensing imagery. Remote Sensing Reviews **13:**207-234.

Curran, L. M., S. N. Trigg, A. K. McDonald, D. Astiani, Y. M. Hardiono, P. Siregar, I. Caniago, and E. Kasischke. 2004. Lowland forest loss in protected areas of Indonesian Borneo. Science **303:**1000-1004.

Daily, G. C., editor. 1997. Nature's services: societal dependence on natural ecosystems. Island Press, Washington, D.C.

Das, K. K., S. A. Ravan, S. K. Negi, A. Jain, and P. S. Roy. 1996. Forest cover monitoring using remote sensing and GIS: a case study in the Dhaulkhand Range of Rajaji National Park, Uttar Pradesh. Journal of the Indian Society for Remote Sensing **24:**33-42.

Datta, R., and G. S. Dutt. 1981. Producer gas engines in villages of less-developed countries. Science **213:**731-736.

DeFries, R. S., M. Hansen, J. R. G. Townshend, and R. Sohlberg. 1998. Global land cover classifications at 8 km spatial resolution: the use of training data derived from Landsat imagery in decision tree classifiers. International Journal of Remote Sensing. **19:**3141-3168.

DeFries, R. S., J. R. G. Townshend, and M. Hansen. 1999. Continuous fields of vegetation characteristics at the global scale at 1km resolution. Journal of Geophysical Research **104:**16911-16925.

DeFries, R. S., M. Hansen, J. R. G. Townshend, A. Janetos, and T. Loveland. 2000. A new global data set of percent tree cover derived from remote sensing. Global Change Biology **6:**247-254.

DeFries, R. S., A. Hansen, A. C. Newton, and M. C. Hansen. 2005. Increasing isolation of protected areas in tropical forests over the past twenty years. Ecological Applications **15:**19-26.

Dinerstein, E., G. Bryja, J. Forrest, A. Heydlauff, J. Ginsberg, S. Klenzendorf, P. Leimgruber, C. Loucks, T. O'Brien, E. Sanderson, J. Seidensticker, M. Songer, and E. Wikramanayake. Setting priorities for the conservation and recovery of the world's tigers: 2005-2015. Collaborative Report. Save the Tiger Fund, Washington, D.C.

Eberhardt, K. 2003. A review of challenges to sustainable development in the uplands of Myanmar. Pages 101-111 in Xu Jianchu and S. Mikesell, editors. Landscapes of diversity: indigenous knowledge, sustainable livelihoods and resource governance in montane mainland Southeast Asia. Proceedings of the III Symposium on MMSEA; 2002 August 25-28; Lijiang, P.R. China. Yunnan Science and Technology Press, Kunming, China.

Ehrlich, P. R. 1988. The loss of diversity: causes and consequences. Pages 29-35 in E. O. Wilson, editor. Biodiversity. National Academy Press, Washington, D.C.

Eisenberg, J. F. 1980. The density and biomass of tropical mammals. Pages 34-55 in M. E. Soulé, and B. A. Wilcox, editors. Conservation biology: an evolutionary ecological perspective. Sinauer Associates, Sunderland, United Kingdom.

Environment Monitoring Unit. 2006. Global land cover 2000 database. European Commission Joint Research Center, Brussels, Belgium. Available from: http//www-gem.jrc.it/glc2000 (accessed March 2006).

ERDAS Inc. 1997. ERDAS Tour Guide 8.3. ERDAS Inc., Atlanta, Georgia.

Ervin, J. 2003. Rapid assessment of protected area management effectiveness in four countries. BioScience **53:**833-841.

Fa, J.E., J. Juste, J. P. Del Val, and J. Castroviejo. 1995. Impact of market hunting on mammal species in Equatorial Guinea. Conservation Biology **9:**1107-1115.

Fa, J. E., J. E. Garcia Yuste, and R. Castelo, R. 2000. Bushmeat markets on Bioko Island as a measure of hunting pressure. Conservation Biology **14:**1602-1613.

Fa, J. E., S. F. Ryan, and D. J. Bell. 2005. Hunting vulnerability, ecological characteristics and harvest rates of bushmeat species in afrotropical forests. Biological Conservation **121:**167-176.

Fensholt, R., and I. Sandholt. 2005. Evaluation of MODIS and NOAA AVHRR vegetation indices with in situ measurements in a semi-arid environment. International Journal of Remote Sensing **26:**2561-2594.

Fiallo, E. A., and S. K. Jacobson. 1995. Local communities and protected areas: attitudes of rural residents towards conservation and Machalilla National Park, Ecuador. Environmental Conservation **22:**241-249.

Food and Agriculture Organization. 1995. Global forest resources assessment 1990. FAO Forestry Paper 124. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food and Agriculture Organization. 2001. Global forest resources assessment 2000. FAO Forestry Paper 140. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food and Agriculture Organization. 2003. The Livestock Industries of Thailand. Food and Agriculture Organization, Bangkok, Thailand.

Foody, G. M. 2005. Local characterization of thematic classification accuracy through spatially constrained confusion matrices. International Journal of Remote Sensing **26:**1217-1228.

Foody, G. M., and M. E. J. Cutler. 2003. Tree biodiversity in protected and logged Bornean tropical rain forests and its measurement by satellite remote sensing. Journal of Biogeography **30:**1053-1066.

Fox, J., P. Yonzon, and N. Podger. 1996. Mapping conflicts between biodiversity and human needs in Langtang National Park, Nepal. Conservation Biology **10:**562-569.

Friedl, M. A., D. K. McIver, J. C. F. Hodges, S. Y. Zhang, D. Muchoney, A. H. Stahler, C. E. Woodcock, S. Gopal, A. Schneider, A. Cooper, A. Baccini, F. Gao, and C. Schaaf. 2002. Global land cover mapping from MODIS: algorithms and early results. Remote Sensing of Environment **83:**287-302.

Ganesan, B. 1993. Extraction of non-timber forest products, including fodder and fuelwood, in Mudumalai, India. Economic Botany **47:**268-274

Gautam, A. P., E. L. Webb, and A. Eiumnoh. 2002. GIS assessment of land use/land cover changes associated with community forestry implementation in the middle hills of Nepal. Mountain Research and Development **22:**63-69.

Gentry, A. H. 1984. An overview of Neotropical phytogeographic patterns with an emphasis on Amazonia. Missouri Botanical Garden, St. Louis, Missouri.

Gentry, A. H. 1995. Diversity and floristic composition of neotropical dry forests. Pages 146-194 in S. H. Bullock, H. A. Mooney, and E. Medina, editors. Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

Giri, C., Z. Ahu, and B. Reed. 2005. A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets. Remote Sensing of Environment **94:**123-132.

Goodman, P. S. 2003. Assessing management effectiveness and setting priorities in protected areas in KwaZulu-Natal. BioScience **53:**843-50.

Grainger, A. 1999. Constraints on modeling the deforestation and degradation of tropical open woodlands. Global Ecology and Biogeography **8:**179-190.

Greenberg, J. A., S. C. Kefauver, H. C. Stimson, C. J. Yeaton, and S. L. Ustin. 2005. Survival analysis of a neotropical rainforest using multitemporal satellite imagery. Remote Sensing of Environment **96:**202-211.

Guild, L. S., W. B. Cohen, and J. B. Kauffman. 2004. Detection of deforestation and land conversion in Rondonia, Brazil using change detection techniques. International Journal of Remote Sensing **25:**731-750.

Haertel, V. F., and Y. E. Shimabukuro. 2005. Spectral linear mixing model in low spatial resolution image data. IEEE Transactions on Geoscience and Remote Sensing **43:**2555-2562.

Hansen, M., R. DeFries, J. R. G. Townshend, R. and Sohlberg. 2000. Global land cover classification at 1km resolution using a decision tree classifier. International Journal of Remote Sensing **21:**1331-1365.

Hardin, G. 1968. The tragedy of the commons. Science **162:**1243-1248.

Hegde, R., S. Suryaprakash, L. Achoth, and K. S. Bawa. 1996. Extraction of non-timber forests of Biligiri Rangan Hills, India. I. Contribution to rural income. Economic Botany **50:**243-251.

Heywood, V. H. 1995. Global biodiversity assessment. Cambridge University Press, Cambridge, United Kingdom.

Hirsch, P. 1995. A regional perspective on large dams. As cited in Eberhardt, K. 2003. A review of challenges to sustainable development in the uplands of Myanmar. Pages 101-111 in Xu Jianchu and S. Mikesell, editors. Landscapes of diversity: indigenous knowledge, sustainable livelihoods and resource governance in montane mainland Southeast Asia. Proceedings of the III Symposium on MMSEA; 2002 August 25-28; Lijiang, P.R. China. Yunnan Science and Technology Press, Kunming, China.

Houghton, R. A. 1994. The worldwide extent of land-use change: in the last few centuries, and particularly in the last several decades, effects of land-use change have become global. Bioscience **44:**305-313.

Houghton, R. A., and J. L. Hackler. 1999. Emissions of carbon from forestry and land-use change in tropical Asia. Global Change Biology **5:**481-492.

Houghton, R. A., and J. L. Hackler. 2000. Changes in terrestrial carbon storage in the United States I: The roles of agriculture and forestry. Global Ecology and Biogeography **9:**125-144.

Hubener, H., M. Schmidt, M. Sogalla, and M. Kerschgens. 2005. Simulating evapotranspiration in a semi-arid environment. Theoretical and Applied Climatology **80:**153-167.

Huete, A. K. Didan, T. Miura, E. P. Rodriguez, X. Gao, and L. G. Ferreira. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment **83:**195-213.

Janzen, D. H. 1988. Tropical dry forests: the most endangered major tropical ecosystem. Pages 130-144 in E. O. Wilson, and F. M. Peters, editors. Biodiversity. National Academy Press, Washington, D.C.

Janzen, D.H. 1996. Wildland biodiversity management in the tropics. Pages 411-431 in E.O. Wilson, editor. Biodiversity II. Joseph Henry, Washington, D.C.

Jensen, J. R. 1996. Introductory digital image processing: a remote sensing perspective. 2nd ed. Prentice Hall, Upper Saddle River, New Jersey.

Jensen, J. R., E. W. Ramsey, H. E. Mackey, E. Christensen, and R. Sharitz. 1987. Inland wetlands change detection using aircraft MSS data. Photogrammetric Engineering and Remote Sensing **9:**669-682.

Kalia, A. K. 2000. Biogas as a source of rural energy. Energy Sources **22:**67-76.

King, D., and J. H. Rappole. 2001. Mixed-species bird flocks in dipterocarp forest of north-central Burma (Myanmar). Ibis **143:**380-390.

Koy, K., W. J. McShea, P. Leimgruber, B. N. Haack, and Myint Aung. 2005. Percentage canopy cover - using Landsat imagery to delineate habitat for Myanmar's endangered Eld's deer (*Cervus eldi*). Animal Conservation **8:**289-296.

Kurz, S., 1877. Forest flora of British Burma, Vols. I and II. Office of the Superintendent of Government Printing, Calcutta, India.

Lefsky, M. A., W.B. Cohen, G. G. Parker, D. J. Harding. 2002. Lidar remote sensing for ecosystem studies. BioScience **52:**19-30.

Leimgruber, P., J. B. Gagnon, C. Wemmer, D. S. Kelly, M. A. Songer, and E. R. Selig. 2003. Fragmentation of Asia's remaining wildlands: implications for Asian elephant conservation. Animal Conservation **6:**347-359.

Leimgruber, P., C. A. Christen, and A. Laborderie. 2005. The impact of Landsat satellite monitoring on conservation biology. Environmental Monitoring and Assessment **106:**81-101.

Leimgruber, P., D. S. Kelly, M. K. Steininger, J. Brunner, T. Mueller, and M. A. Songer. 2006. Forest cover change patterns in Myanmar (Burma) 1990-2000. Environmental Conservation **32**:356-364.

Leviton, A. E., G. O. U. Wogan, M. S. Koo, G. R. Zug, R. S. Lucas, and J. V. Vindum. 2003. The dangerously venomous snakes of Myanmar. Proceedings of the California Academy of Sciences **54:**407-462.

Linkie, M. and R. J. Smith. 2004. Mapping and predicting deforestation patterns in the lowlands of Sumatra. Biodiversity and Conservation **13:**1809-1818.

Liu, J., M. Linderman, Z. Ouyang, L. An, J. Yang, and H. Zheng. 2001. Ecological degradation in protected areas: the case of Wolong Nature Reserve for giant pandas. Science **292:**98-101.

Loveland, T. R., B. C. Reed, J. F. Brown, D. O. Ohlen, Z. Zhu, L. Yang, and J. W. Merchant. 2000. Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. International Journal of Remote Sensing **21:**1303-1330.

Lund, H. G. 1999. A 'forest' by any other name… Environmental Science and Policy **2:**125-133.

Lynam, A. J. 2003. A national tiger action plan for the Union of Myanmar. Wildlife Conservation Society, New York, New York.

Maass, J. M. 1995. Conversion of tropical dry forest to pasture and agriculture. Pages 399-422 in S. H. Bullock, H. A. Mooney, and E. Medina, editors. Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

MacKinnon, J. 1996. Review of biodiversity conservation in the Indo-Malayan realm: draft report prepared by the Asia Bureau for Conservation in collaboration with the World Conservation Monitoring Center. The World Bank, Washington, D.C.

Mares, M. A. 1992. Neotropical mammals and the myth of Amazonian diversity. Science **233:**734-739.

Maselli, F. 2004. Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. Remote Sensing of Environment **89:**423-433.

Matthews, E. 2001. Forest Briefing No. 1: understanding the FRA 2000. World Resources Institute, Washington, D.C.

McGarigal, K., S. A. Cushman, M. C. Neel, and E. Ene. 2002. FRAGSTATS: spatial pattern analysis program for categorical maps [computer software program]. University of Massachusetts, Amherst, Massachusetts. Available from http://www.umass.edu/landeco/research/fragstats/fragstats.html

McShea, W. J., P. Leimgruber, Myint Aung, S. L. Monfort, and C. Wemmer. 1999. Range collapse of tropical cervid (*Cervus eldi*) and the extent of remaining habitat in central Myanmar. Animal Conservation **2:**173-183.

McShea, W. J., M. Aung, D. Poszig, C. Wemmer, and S. L. Monfort. 2001. Forage, habitat use, and sexual segregation by a tropical deer (*Cervus eldi thamin*) in a dipterocarp forest. Journal of Mammalogy **82:**848-857.

Medina, E. 1995. Diversity of life forms of higher plants in neotropical dry forests. Pages 221-242 in S. H. Bullock, H. A. Mooney, and E. Medina, editors. Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

Menzies, N. K. 1995. The changing dynamics of shifting cultivation practices in upland southwest China. As cited in Eberhardt, K. 2003. A review of challenges to sustainable development in the uplands of Myanmar. Pages 101-111 in Xu Jianchu and S. Mikesell, editors. Landscapes of diversity: indigenous knowledge, sustainable livelihoods and resource governance in montane mainland Southeast Asia. Proceedings of the III Symposium on MMSEA; 2002 August 25-28; Lijiang, P.R. China. Yunnan Science and Technology Press, Kunming, China.

Miles, L., A. C. Newton, R. S. DeFries, C. Ravilious, I. May, S. Blyth, V. Kapos, and J. E. Gordon. 2006. A global overview of the conservation status of tropical dry forests. Journal of Biogeography **33:**491-505.

Ministry of Information. 2002. Myanmar facts and figures. Yangon: Ministry of Information, University of Myanmar. As cited in Eberhardt, K. 2003. A review of challenges to sustainable development in the uplands of Myanmar. Page 107 in Xu Jianchu and S. Mikesell, editors. Landscapes of diversity: indigenous knowledge, sustainable livelihoods and resource governance in montane mainland Southeast Asia. Proceedings of the III Symposium on MMSEA; 2002 August 25-28; Lijiang, P.R. China. Yunnan Science and Technology Press, Kunming, China.

Mishra, C., and Rawat, G. S. 1998. Livestock grazing and biodiversity conservation: comments on Saberwal. Conservation Biology **12:**712-714.

Mooney, H. A., S. H. Bullock, and E. Medina. 1995. Introduction. Pages 1-8 in S. H. Bullock, H. A. Mooney, and E. Medina, editors. Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

Murali, K. S., U. Shankar, R. U. Shaanker, K. N. Ganeshaiah, and K. S. Bawa. 1996. Extraction of non-timber forest products in the forests of Biligiri Rangan Hills, India II. Impact of NTFP extraction on regeneration, population structure, and species composition. Economic Botany **50:**252-269.

Murphy, P., and A. E. Lugo. 1986. Ecology of tropical dry forests. Annual Review of Ecology and Systematics **17:**67-88.

Mya Maung. 1998. The Burma road to capitalism. Praegar Publishing. Westport, Connecticut.

Myat Mon. 2000. The economic position of women in Burma. Asian Studies Review **2492:**223-255.

Myers, N. 1984. The primary source: tropical forests and our future. Norton, New York.

Myint Aung. 2006. Policy and practice in Myanmar's protected area system. Journal of Environmental Management (in press).

Myint Aung, Khaing Khaing Swe, Thida Oo, Kyaw Kyaw Moe, P. Leimgruber, T. Allendorf, C. Duncan, and C. Wemmer. 2004. The environmental history of Chatthin Wildlife Sanctuary, a protected area in Myanmar (Burma). Journal of Environmental Management **72:**205-216.

Nagendra, H. 2002. Tenure and forest conditions: community forestry in the Nepal Terai. Environmental Conservation **29:**530-539.

Nijaguna, B.T. 2002. Biogas technology. New Age Publishers, New Delhi, India.

Noss, R. F., E. Dinerstein, B. Gilbert, M. Gilpin, B. J. Miller, J. Terborgh, and S. Trombulak. 1999. Core areas: where nature reigns. Pages 99-128 in M. E. Soule and J. Terborgh, editors. Continental conservation: scientific foundations of regional reserve networks. Island Press, Washington, D.C.

Novacek, M. J., and E. E. Cleland. 2001. The current biodiversity extinction event: scenarios for mitigation and recovery. Proceedings of the National Academy of Sciences of the United States **98:**5466-5470.

Olson, E. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. D. Underwood, J. A. D'Amico, I. Itoua, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, R. H. Ricketts, Y. Kura, J. F. Lamoreux, W. W. Wettengel, P. Hedao, and K. R. Kassem. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. BioScience **51:**933-938.

Palm, C. A., R. A. Houghton, and J. M. Melillo. 1986. Atmospheric carbon dioxide from deforestation in Southeast Asia. Biotropica **18:**1986-1988.

Peres, C. A. 1994. Indigenous reserves and nature conservation in Amazonian forests. Conservation Biology **8:**586-589.

Peres, C. A. 2000. Effects of subsistence hunting on vertebrate community structure in Amazonian forests. Conservation Biology **14:**240-253.

Peres, C. A., and J. W. Terborgh. 1995. Amazonian nature reserves: an analysis of the defensibility status of existing conservation units and design criteria for the future. Conservation Biology **9:**34-46.

Rabinowitz, A., G. B. Schaller, and U Uga. 1995. A survey to assess the status of Sumatran rhinoceros and other large mammal species in Htamanthi Wildlife Sanctuary, Myanmar. Oryx **29:**123-128.

Rao, M., A. Rabinowitz, and Saw Tun Khaing. 2002. Status review of the protected-area system in Myanmar, with recommendations for conservation planning. Conservation Biology **16:**360-368.

Raven, P. H. 1998. Our diminishing tropical forests. Pages 119-122 in E. O. Wilson, and F. M. Peters, editors. Biodiversity. National Academy Press, Washington, D.C.

Reddy, S. R. C., and S. P. Chakravarty. 1999. Forest dependence and income distribution in subsistence economy: evidence from India. World Development **27:**1141-1149.

Redford, K. H. 1992. The empty forest. Bioscience **42(6):**412-422.

Redford, K. H., and A. M. Stearman. 1993. Forest-dwelling native Amazonians and the conservation of biodiversity: interests in common or in collision? Conservation Biology **7:**248-255.

Refisch, J., and I. Kone. 2005. Market hunting in the Tai Region Cote d'Ivoire and implications for monkey populations. International Journal of Primatology **26:**621-629.

Roy, P. S., S. Agrawal, P. Joshi, and Y. Shukla. 2003. The land cover map for Southern Asia for the year 2000. GLC2000 database, European Commission Joint Research Centre, Brussels, Belgium. Available from http://www-gem.jrc.it/glc2000.

Ruangpanit, N. 1995. Tropical seasonal forests in monsoon Asia: with emphasis on continental Southeast Asia. Vegetation **121:**31-40.

Rundel, P. W., and K. Boonpragrob. 1995. Dry forest ecosystems of Thailand. Pages 93-123 in S. H. Bullock, H. A. Mooney, and E. Medina, editors. Seasonally dry tropical forests. Cambridge University Press, Cambridge, United Kingdom.

Running, S. W., C. Justice, V. Salomonson, D. Hall, J. Barker, Y. Kaufman, Y., A. Strahler, A. Huete, J. P. Muller, V. Vanderbilt, Z. M. Wan, P. Teillet, and D. Carneggie. 1994. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. International Journal of Remote Sensing **15:**3587-3620.

Rutchey, K., and L. Vilcheck. 1994. Development of an Everglades vegetation map using a SPOT Image and the Global Positioning System. Photogrammetric Engineering and Remote Sensing **60:**767

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Sykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global biodiversity scenarios for the year 2100. Science **287:**1770-1774.

Sanchez-Azofeifa, G. A., M. Kalacska, M. Quesada, J. C. Clavo-Alvarado, J. M. Nassar, and J. P. Rodriguez. 2005. Need for integrated research for a sustainable future in tropical dry forests. Conservation Biology **19:**285-286.

Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. BioScience **52:**891-904.

Scepan, J., 1999. Thematic validation of high-resolution global land-cover data sets. Photogrammetric Engineering and Remote Sensing **65:**1051-1060.

Shaw, R. P. 1989. Rapid population growth and environmental degradation: ultimate versus proximate factors. Environmental Conservation **16:**199-208.

Singh, V.P., and J. S. Singh. 1989. Man and forests: a case-study from the dry tropics of India. Environmental Conservation **16:**129-136.

Skole, D., and C. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. Science **260:**1905-1910.

Songer, M. A., Myint Aung, Khaing Khaing Swe, Thida Oo, C. Wemmer, R. DeFries, and P. Leimgruber. The impact of local communities on a dry forest sanctuary - a case study from Upper Myanmar (Burma) (submitted to Ambio).

Stamp, L. D.1925. The vegetation of Burma from an ecological standpoint. Thacker, Spink & Company, Calcutta, India.

Steele, B. M., J. C. Winne, and R. L. Redmond. 1998. Estimation and mapping of misclassification probabilities for thematic land cover maps. Remote Sensing of Environment **66:**192-202.

Stiles, D. 1994. Tribals and trade: a strategy for Cultural and ecological survival. Ambio **23(2):**106-111.

Stott, P. 1990. Stability and stress in the savanna forests of mainland South-East Asia. Journal of Biogeography **17:**373-383.

Strahler, A. 2003. Validation of the consistent-year v003 MODIS land cover product. Boston University, Boston, Massachusetts. Available from http://www-modis.bu.edu/landcover/userguidelc/consistent.htm (accessed March 2006).

Strahler, A., D. Muchoney, J. Borak, M. Friedl, S. Gopal, E. Lambin, and A. Moody. 1999. MODIS land cover product: algorithm theoretical basis document (ATBD) version 5.0. Boston University, Boston, Massachusetts.

Struhsaker, T. T., P. J. Struhsaker, and K. S. Siex. 2005. Conserving Africa's rain forests: problems in protected areas and possible solutions. Biological Conservation **123:**45-54.

Sukumar, R. 2003. The living elephants: evolutionary ecology, behavior, and conservation. Oxford University Press, Oxford, United Kingdom.

Sutton, S. L., T. C. Whitmore, and A. C. Chadwick, editors. 1984. Tropical rain forests: ecology and management. Blackwell, Oxford, United Kingdom.

Thuiller, W., O. Broennimann, G. Hughes, J. R. M. Alkemades, G. F. Midgley, and F. Corsi. 2006. Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. Global Change Biology **12:**424-440.

Tordoff, J., J. C. Eames, K. Eberhardt, M. C. Baltzer, P. Davidson, P. Leimgruber, U Uga, and U Aung Than. 2005. Myanmar: investment opportunities in biodiversity conservation. Birdlife International, Cambridge, United Kingdom.

Treitz, P., and P. Howarth. High spatial resolution remote sensing data for forest ecosystem classification – an examination of spatial scale. Remote Sensing of Environment **72:**268-289.

Trigg, S. N. 2006. Utility of Landsat 7 satellite data for continued monitoring of forest cover change in protected areas in Southeast Asia. Singapore Journal of Tropical Geography **27:**49

Tucker, C. J. 1979. Red and near-infrared linear combinations for monitoring vegetation. Remote Sensing of Environment **8:**127-150.

Tucker, C. J., and J. R. G. Townshend. 2000. Strategies for monitoring tropical deforestation using satellite data. International Journal of Remote Sensing **21(6-7):**1461-1471.

Tucker, C. J., D. M. Grant, and J. Dykstra. 2004. NASA's global orthorectified Landsat data set. Photogrammetric Engineering and Remote Sensing **70:**313-323.

Uhl, C., P. Barreto, A. Verissimo, E. Vidal, P. Amaral, A. C. Barros, C. Souze, Jr., J. Johns, and J. Gerwing. 1997. Natural resource management in the Brazilian Amazon. BioScience **47:**160-168.

van Schendel, W. 1991. Three deltas: accumulation and poverty in rural Burma, Bengal and South India. Sage Publication, New Delhi, India.

van Leeuwen, W. J. D., A. R. Huete and T. W. Laing. 1999. MODIS vegetation index compositing approach: a prototype with AVHRR data. Remote Sensing of Environment **69:**264–280.

Verbyla, D. 1995. Satellite remote sensing of natural resources. CRC Press, Boca Raton, Forida.

Vina, A., F. R. Echavarria, and D. C. Rundquist. 2004. Satellite change detection analysis of deforestation rates and patterns along the Colombia – Ecuador border. Ambio **33:**118-125.

Vitousek, P. M. 1994. Beyond global warming: ecology and global change. Ecology **75:**1861-1876.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science **277:**494-499.

Vogelmann, J. C., S. M. Howard, L. Yang, C. R. Larson, B. D. Wylie, and N. Van Driel. 2001. Completion of the 1990s national land cover dataset for the conterminous United Sates from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing **67:**650-662.

Walther, G-R, E. Post, P. Convey, A. Menzel, C. Parmeson, T. J. C Beebee, J-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature **416:**389-395.

Wemmer, C., W. J. Kress, and G. Zug. 2004. Smithsonian collaborations in Myanmar: a compilation of projects and activities between 1994-2003. Smithsonian Institution, Washington, D.C.

White, M. A., J. D. Shaw, and R. D. Ramsey. 2005. Accuracy assessment of the vegetation continuous field tree cover product using 3954 ground plots in the south-western USA. International Journal of Remote Sensing **26:**2699-2704.

Wickham, J. D., S. V. Stehman, J. H. Smith, T. G. Wade, and L. Yang. 2004. A priori evaluation of two-stage cluster sampling for accuracy assessment of large-area land-cover maps. International Journal of Remote Sensing **6:**1235-1252.

Wickramasinghe, A., M. R. Perez, and J. M. Blockhus. 1996. Nontimber forest product gathering in Ritigala Forest (Sri Lanka): household strategies and community differentiation. Human Ecology **24:**493-519.

Wikramanayake, E., E. Dinerstein, C. J. Loucks, D. M. Olson, J. Morrison, J. Lamoreux, M. McKnight, and P. Hedao. 2002. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press, Washington, D.C.

Wilby, R. L., and G. L. W. Perry. 2006. Climate change, biodiversity, and the urban environment: a critical review based on London, UK. Progress in Physical Geography **30:**73-98.

Wilkie, D. S. 1996. Remote sensing imagery for natural resources monitoring: a guide for first-time users. Columbia University Press, New York, New York.

Wilkie, D. S., M. Starkey, K. Abernethy, E. Nstame Effa, P. Telfer, and R.Godoy. 2005. Role of prices and wealth in consumer demand for bushmeat in Gabon, Central Africa. Conservation Biology **19:**268-274.

Wilson, E.O. 1992. The diversity of life. Harvard University Press, Cambridge, United Kingdom.

Woodwell, G. M., J. E. Hobbie, R. A. Houghton, J. M. Melillo, B. Moore, B. J. Peterson, and G. R. Shaver. 1983. Global deforestation: contribution to atmospheric carbon dioxide. Science **222:**1081-1086.

World Health Organization. 2005. Ecosystems and human well-being: health synthesis a report of the Millennium Ecosystem Assessment. World Health Organization, Geneva, Switzerland.

Yonzon, P. B., and M. L. Hunter Jr. 1991. Cheese, tourists, and red pandas in the Nepal Himalayas. Conservation Biology **5:**196-202.

Zheng, D., D.O. Wallin, and Z. Hao. 1997. Rates and patterns of landscape change between 1972 and 1988 in the Changbai Mountain area of China and North Korea. Landscape Ecology **12:**241-254.