Leaflet No. 31/2019

The Republic of the Union of Myanmar

Ministry of Natural Resources and Environmental Conservation

Forest Department

Spatial and temporal analysis of the forest cover change on a protected area in Southern Myanmar using remote sensing data: Applications to forest conservation

Thant Zin Maw, Staff Officer

Forest Department

December, 2019

Contents

Remote sensing နည်းပညာအား အသုံးပြု၍ မြန်မာပြည်တောင်ပိုင်းရှိ သဘာဝထိန်းသိမ်းရေးနယ်မြေတစ်ခုအတွင်း နေရာဒေသနှင့် အချိန်ကာအလိုက် သစ်တောဖုံးလွှမ်းမှုပြောင်းလဲနေမှုအခြေအနေအား ဆန်းစစ်လေ့လာခြင်း

သန့်ဇင်မော် (ဦးစီးအရာရှိ)
Dr. Mamorou Kanzaki (ပါမောက္ခ)

စာတမ်းအကျဉ်း

မြန်မာနိုင်ငံတောင်ဘက်ပိုင်းတွင် လူဦးရေများ တိုးပွားလာသည့်အတွက်ကြောင့် သစ်တောဧရိယာသည် တဖြည်းဖြည်းလျော့နည်းလာပြီး အခြားသော မြေအသုံးချမှုနှင့် မြေဖုံးလွှမ်းမှုအခြေအနေသို့ ပြောင်းလဲလျက်ရှိနေပါသည်။ ဤသုတေသနသည် တနင်္သာရီ သဘာဝကြိုးဝိုင်းတော (Tanintharyii Nature Reserve– TNR) အမည်ရှိ ဧရိယာ ၁၇၀၀ စတုရန်း ကီလိုမီတာခန့် ကျယ်ဝန်းသည့် သဘာဝထိန်းသိမ်းရေးနယ်မြေ၏ နှစ်ပေါင်း ၂၇ နှစ်အတွင်း သစ်တောဖုံးလွှမ်းမှု ပြောင်းလဲနေမှု အခြေအနေတို့ကို Landsat ဂြိုဟ်တု ဓာတ်ပုံများ အသုံးပြု ၍ လေ့လာထားပြီး ထိန်းသိမ်းရေးနယ်မြေအဖြစ် မသတ်မှတ်ခင်နှင့် သတ်မှတ် တည်ထောင်ပြီးနောက် အချိန်ကာလ နှစ်မျိုးအတွင်းရှိ သစ်တောများတည်ရှိမှု အနေအထားနှင့် ခြားနားချက်အခြေအနေတို့ကို လေ့လာထားခြင်းဖြစ်ပါသည်။ တနင်္သာရီသဘာဝကြိုးဝိုင်းတောအား သဘာဝထိန်းသိမ်းရေးနယ်မြေအဖြစ် ၂၀၀၅ ခုနှစ်တွင် စတင်ကြေငြာခဲ့ပြီး မြန်မာနိုင်ငံ သစ်တောဦးစီးဌာနမှ သဘာဝနေရင်းဒေသများနှင့် ဇီဝမျိုးစုံမျိုးကွဲများကို ထိန်းသိမ်းစီမံ အုပ်ချုပ်လျက်ရှိကာ နိုင်ငံတကာ သဘာဝဓာတ်ငွေ့ကုမ္ပဏီသုံးခုမှ ရေနံနှင့်သဘာဝဓာတ်ငွေ့ ပိုက်လိုင်းများသည် ကြိုးဝိုင်းတစ်လျှောက် ဖြတ်သန်းဖောက်လုပ်ခဲ့သည့်အတွက်ကြောင့် လျော်ကြေးအနေဖြင့် ရံပုံငွေကြေး ထောက်ပံ့ပေးလျက် ရှိပါသည်။ ပထမပိုင်းအနေဖြင့် သုတေသနပြု လေ့လာမည့် ဒေသ၏ ၁၉၉၀၊ ၂၀၀၆ နှင့် ၂၀၁၇ ခုနှစ်များ၌ ဖြစ်ပွားလျက် ရှိခဲ့သည့်မြေအသုံးချမှု မြေဖုံးလွှမ်းမှု ပြောင်းလဲမှုအခြေအနေတို့အပေါ် နေရာဒေသနှင့် အချိန်ကာလ အပိုင်းအခြားအလိုက် မြေအသုံးချမှု မြေဖုံးလွှမ်းမှုဆိုင်ရာ အမျိုးအစား (၈) မျိုး အဖြစ် ခွဲခြားသတ်မှတ်၍ ဆန်းစစ်လေ့ လာခဲ့ပါသည်။ သဘာဝ ထိန်းသိမ်းရေးနယ်မြေ နယ်နိမိတ်မှ ၁၀ ကီလိုမီတာအကွာအထိ ကြားခံနယ်မြေအဖြစ် ဖန်တီးကာ သဘာဝ ထိန်းသိမ်းရေး နယ်မြေအတွင်းနှင့် ပြင်ပ ၁၀ ကီလိုမီတာပတ်လည်ရှိ မြေအသုံးချမှု မြေဖုံးလွှမ်းမှု ပြောင်းလဲမှု အခြေအနေတို့ကို နှိုင်းယှဉ်လေ့လာကာ သဘာဝ ထိန်းသိမ်းရေး နယ်မြေစီမံအုပ်ချုပ်မှု အခြေအနေတို့ကို အကဲဖြတ်လေ့လာခဲ့ပါသည်။ ဒုတိယပိုင်းတွင် မြေပြင် လက်တွေ့ ကွင်းဆင်း လေ့လာမှုနှင့် သဘာဝထိန်းသိမ်းရေး နယ်မြေဝန်ထမ်းများ၊ ကျေးရွာဒေသခံများနှင့် ကျေးရွာ လူကြီးများနှင့်အတူ မေးမြန်းစူးစမ်းခြင်းတို့ဖြင့် ပေါင်းစပ်ကာ မြေအသုံးချမှု မြေဖုံးလွှမ်းမှု ပြောင်းလဲမှုကို သက်ရောက်ဖြစ်ပေါ်လျက်ရှိနေသော အဓိကအကြောင်းအရာများ ကိုလည်း လေ့လာခဲ့ပါသည်။ ဤသုတေသနမှ အချိန်ကာလ(၂၇) နှစ်တာ ကာလအတွင်း သဘာဝ ထိန်းသိမ်းရေး နယ်မြေအတွင်းရှိ ရွက်အုပ်ပိတ်တောများသည် မြေပြန့်ဒေသများတွင် သိသာထင်ရှားစွာ ထိခိုက်လျော့နည်းလျက်ရှိပါကြောင်းနှင့် သဘာဝ

ထိန်းသိမ်းရေးနယ်မြေအဖြစ် မသတ်မှတ်ခင်အချိန် ၁၉၉၀ ခုနှစ်တွင် ၈၁ % ၊ ၂၀၀၆ ခုနှစ်တွင် ၆၇ % နှင့် ၂၀၁၇ ခုနှစ်တွင် ၅၉ % အထိ အချိန်ကာလအလိုက် အဆက်မပြတ် လျော့နည်းလာကြောင်း တွေ့ရှိ ခဲ့ပါသည်။ သုတေသနရလာဒ်များသည် သဘာဝထိန်းသိမ်းရေး နယ်မြေအဖြစ် မသတ်မှတ်ခင် အချိန် (၁၉၉၀ မှ ၂၀၀၆ ခုနှစ်အတွင်း)တွင် သစ်တောအတန်းအစားကျဆင်းမှုနှုန်းသည် ပျှမ်းမျှ အားဖြင့် နှစ်စဉ် ၀.၄၁% မှ တည်ထောင်ပြီးချိန် (၂၀၀၆ မှ ၂၀၁၇ ခုနှစ်အတွင်း)၌ ၀.၇၂% အထိ မြင့်တက်လာကြောင်း တွေ့ရှိရပြီး တစ်ဖက်မှာလည်း နှစ်စဉ်ပျှမ်းမျှသစ်တော ပြုန်းတီးမှုနှုန်း သည် ၁၉၉၀ ခုနှစ်မှ ၂၀၀၆ ခုနှစ်ကာလအတွင်း ၀.၁၂% မှ ၂၀၀၆ ခုနှစ်မှ ၂၀၁၇ ခုနှစ် ကာလ တွင် ၀.၅၂% အထိ မြင့်တက်လာခဲ့ကြောင်း တွေ့ရှိရပါသည်။ ဒေသခံတိုင်းရင်းသား ကျေးရွာသားများနှင့် ပြင်ပမှ ခေတ္တအခြေချနေထိုင်လာသူ နှစ်မျိုးလုံးတို့၏ သစ်ထုတ်ယူခြင်းနှင့် ကျေးရွာများတစ်ဝိုက်တွင် စိုက်ပျိုးမြေ ချဲ့ထွင်လာခြင်းတို့ကြောင့် သဘာဝထိန်းသိမ်းရေးနယ်မြေတွင် ကာကွယ်တောအဖြစ် မထိန်းသိမ်းမီနှင့် သတ်မှတ်ထိန်း သိမ်းပြီးအချိန်ကာလ နှစ်မျိုးလုံး၌ သစ်တောအတန်း အစားကျဆင်းခြင်းနှင့် သစ်တောပြုန်းတီးခြင်း ဖြစ်ရပ်နှစ်မျိုးလုံးတို့ကို လေ့လာတွေ့ရှိခဲ့ပါသည်။ ထို့ပြင် ဒေသခံများနှင့် ကာကွယ်တော အုပ်ချုပ်ရေးပိုင်းလူကြီးများနှင့်အတူ ဆွေးနွေးပြောကြားချက်များမှ သဘာဝဓာတ်ငွေ့ပိုက်လိုင်း စီမံကိန်းဝင်ရောက်လာ ချိန်မှစတင်၍ စီမံကိန်း၏ ရံပုံငွေအထောက်အပံ့ ပေးထားသည့် အတွက်ကြောင့် ကျေးရွာ ဖွံ့ဖြိုးရေးအစီအစဉ်များ ပေါ်ပေါက်လာကာ ကြားခံနယ်မြေအတွင်းရှိ တိုင်းရင်းသားဒေသခံများသည် ရွှေ့ပြောင်းတောင်ယာစနစ်မှ ဥယျာဉ်ခြံများနှင့် ရာဘာစိုက်ခင်းများအကြီးအကျယ် စိုက်ပျိုး တည်ထောင်ခြင်းတို့ဆီသို့ ပြောင်းလဲတည်ထောင်လာကာ ဒေသခံပြည်သူတို့၏ လူနေမှုဘဝ တဖြည်းဖြည်းပြောင်းလဲပြီး တိုးတက်မြင့်မားလာကြောင်း လေ့လာ တွေ့ရှိခဲ့ပါသည်။ သဘာဝထိန်းသိမ်းရေး နယ်မြေအပေါ် သစ်တောဦးစီးဌာန၏ စီမံအုပ်ချုပ်မှု နည်းစနစ်နှင့် ထိန်းသိမ်း ကာကွယ်ရေး လုပ်ငန်းများသည် အားနည်းချက်များစွာရှိနေပြီး လက်ရှိ ထက်ပိုမို တိုးတက် ကောင်းမွန်လာရန် လိုအပ်လျက်ရှိနေကြောင်းကိုလည်း သုတေသန ရလာဒ်များ၏ အချုပ်အနေဖြင့် တွေ့ရှိခဲ့ရပါသည်။ TNR ၏အနာဂတ် စီမံအုပ်ချုပ်မှုကို ဒေသခံပြည်သူများ၏ ပူးပေါင်းပါဝင် ဆောင်ရွက်ချက်များနှင့်အတူ သဘာဝခရီးသွားဒေသတစ်ခုအဖြစ် တည်ထောင်ပြီး ဝင်ငွေများဖန်တီးနိုင်ခြင်း၊ ကျေးရွာပိုင် သစ်တောစိုက်ခင်းများ တည်ထောင်ခြင်းနှင့် သစ်တော ဂေဟဗေဒစနစ် ထိန်းသိမ်းခြင်းအား မထိခိုက်စေသည့် ဖွံ့ဖြိုးရေးစီမံကိန်း လုပ်ငန်းများအစ ပျိုး၍ ဆောင်ရွက်ခြင်းစသည်တို့ကို ဦးစားပေး ဆောင်ရွက်သင့်ပါသည်။

Spatial and temporal analysis of the forest cover change on a protected area in Southern Myanmar using remote sensing data: Applications to forest conservation

Thant Zin Maw (Staff Officer) [a,b*]
Dr. Mamorou Kanzaki (Professor)[a]

[a] *Division of Forest and Biomaterials Science, Faculty of Agriculture, Kyoto University, Japan*
[b] *Remote Sensing & GIS Section, Planning and Statistics Division, Forest Department, Ministry of Natural Resources and Environmental Conservation, Republic of Myanmar*

Abstract

As the human population increases in Southern Myanmar, forest area is gradually shrinking and being transformed into other land use land cover types. This study investigated the forest cover dynamics in the protected area (PA), named as Tanintharyii Nature Reserve (TNR). The area covers approximately 1700 km2. TNR was declared as a PA in 2005 under the management of Myanmar Forest Department (FD), by the financial support of three International Gas Pipeline Companies as compensation for the pipelines' passing through the reserve forest. Firstly, land use/land cover (LULC) change of the study area for the years 1990, 2006, and 2017 were spatially and temporally analyzed, with LULC eight categories. The comparison of the LULC between PA and a 10-km buffer zonation surrounding it was also undertaken to evaluate the PA management effectiveness. Secondly, the most determinant factors contributing to LULC change were analyzed from the information of field observation and key informant interview. During the study period, the dense forest in the PA was decreased markedly at low elevations, with the overall cover by dense forest decreasing from 81% in 1990 to 67% in 2006 before protected and continuously declined to 59% in 2017. The results showed that the average annual forest degradation rate increased from −0.41% yr-1 before protection to −0.72% yr-1 after protection, and the deforestation rate increased from −0.12% yr-1 before protection to −0.52% yr-1 after protection. Inside the PA, forest degradation and deforestation were found both before and after protection in 2005 due to agricultural land expansion around the settled villages and logging activities by the ethnic villagers and outsiders. Based on the interviews and observation results, we concluded that in the buffer zone, the livelihood patterns of the local people changed gradually from shifting cultivation to fruit orchards and rubber plantations due to regional development programs, that was financially supported by the pipeline projects. This study indicated that the FD management practices in the PA were needed to improve. The future management of the TNR should prioritize the initiation of eco-development projects, the establishment of village-owned tree plantations, and eco-tourism, together with good collaboration between the local forces and central government.

Keywords: Land Use Land Cover Change, Forest cover change, Deforestation, Protected area, Landsat image, Remote sensing and GIS

Spatial and Temporal Analysis of the Forest Cover Change on a Protected Area in Southern Myanmar Using Remote Sensing Data: Applications to Forest Conservation

1. Introduction

Tropical forests continue to be depleted, both qu

antitatively and qualitatively, at ever-increasing rates (Hadley, M. and Lanly, 1982; Melillo et al, 1985; Molofsky et al, 1985; Myers, 1980, 1985). The conversion of natural habitat to other land uses is the major driving force behind worldwide biodiversity loss (Sala et al., 2000). Shifting cultivation has been blamed for large-scale deforestation and forest degradation in tropical region (Mukul & Herbohn, 2016).

Deforestation is particularly severe in Southeast Asia, such as lowland rain forests, are being destroyed at relative rates that are higher than those of other tropical regions (Achard et al., 2002), due to agricultural expansion, logging, habitat fragmentation and urbanization. South East Asia, local and regional land-use and development policies have been developed to reduce shifting cultivation due to a perceived negative impact on environment (Fox et al., 2009; van Vliet et al., 2012). Southeast Asian uplands, there is an agricultural transition underway from subsistence production based on shifting cultivation to commercial production based on tree crops (Manivong & Cramb, 2008).

The establishment and management of protected areas (PAs) is important in protecting landscapes, achieving biodiversity conservation, and delivering essential ecosystem services (Watson et al, 2014). Many local communities, particularly in developing countries, are profoundly dependent on protected areas for energy, employment, medicine, and other subsistence needs (Bahuguna, 2000).

Studies have shown that these lands are generally effective in reducing deforestation within their boundaries, although some protected areas were not significant in reducing forest loss (Naughton-Treves et al., 2005). Many protected areas struggle in maintaining and improving their relationship with communities given resource and land-use restrictions, and equivocal governance approaches (Djomo Nana & Ngameni Tchamadeu, 2014; Snyman, 2012).

In 1990, more than half of the remaining forests in mainland Southeast Asia could be found in Myanmar (Dinerstein et al., 1993). Myanmar’s burgeoning populations and high poverty levels have increased pressure on its natural resources and protected areas (PAs, Lwin et al., 1990). Myanmar’s protected area (PA) system began nearly 150 years ago under royal patronage (Myint Aung, 2007). In Myanmar, Protected Area System (PAS) is administered in accordance with the Protection of Wildlife and Wild Plants and the Conservation of Protected Areas Law (1994) and Myanmar Forest Policy long run.

According to the data from Forest Resource Assessment (FRA in 2005) indicated 50.2% (FAO, 2006), then is rapidly decreasing from about 46.96% in (FAO, 2010) to about 42.92% (UN FAO, 2015) of the total land area (676,577 km^2). Agricultural expansion, shifting cultivation, conversion of forest to plantations are the main causes of habitat degradation and loss (FAO, 2010). AGRAWAL et al., 1999 said that community must be examined and considered in the context of development and conservation by focusing on the multiple interests and actors within communities, on how these actors influence decision-making, and on the internal and external institutions that shape the decision-making process.

As the human population increases in Southern Myanmar, forest area is gradually shrinking and being transformed into other land use land cover types. Historical baselines of forest cover are needed to understand the causes and consequences of recent changes and to assess the effectiveness of land-use policies (Kim et al., 2014). The reason why I would like to carry out this research is very limited and updated international scientific study about the investigation of deforestation rates in this region. This research area has been experiencing with several threats to forest, especially land use land cover change, surrounding Taninthayii Nature Reserve (TNR).

Understanding the rates of deforestation, and spatial and temporal change of forest cover will contribute to plan sustainable forest management and biodiversity conservation. Thus, this study evaluated land use land cover (LULC) change by integrating high technology Remote Sensing, GIS methods, Landsat satellite images and key informant interviews to examine the conditions and livelihood pattern in finding out the determinant factors on land use land cover change, focusing on forest cover change (namely deforestation). The primary purpose of this study is to contribute the scientific information and knowledge essential to policy formulation, biodiversity conservation planning and land resource management. The first objective of this research was to understand the spatial and temporal change of forest to other land use land cover- for which we needed to compare within the protected area, and outside in the adjacent surrounding the landscape. More specifically, we aim to answer the following three research questions

a) How is spatially and temporally changing from forests to other land use land cover (LULC) inside PA and their surrounding areas?
b) What is the annual rate of deforestation and forest degradation inside PA and their surrounding areas?
c) What are the situations and effectiveness of PAS management in Myanmar?

2. Materials and Methods

2.1 Study Area

The study area was selected in a strictly protected area named as Taninthayii Nature Reserve (TNR), located in Taninthayii Region (formerly called Division), Southern Myanmar (Fig. 1). It extends approximately 1700 km^2, locates in 14^o 20” N to 14^o 57” N latitude and 98^o 5” E and 98^o 31” E longitude. The average minimum and maximum temperature are from 13-37 ^oC during the period of 10 years (2008-2017). The average annual rainfall is 5363 mm during the period of 10 years (2007-2016) (unpublished official data, Dawei District Forest Department, 2017). The elevation is ranged from 15 m near the sea side to 1400 m alongside of the Thailand boundary.

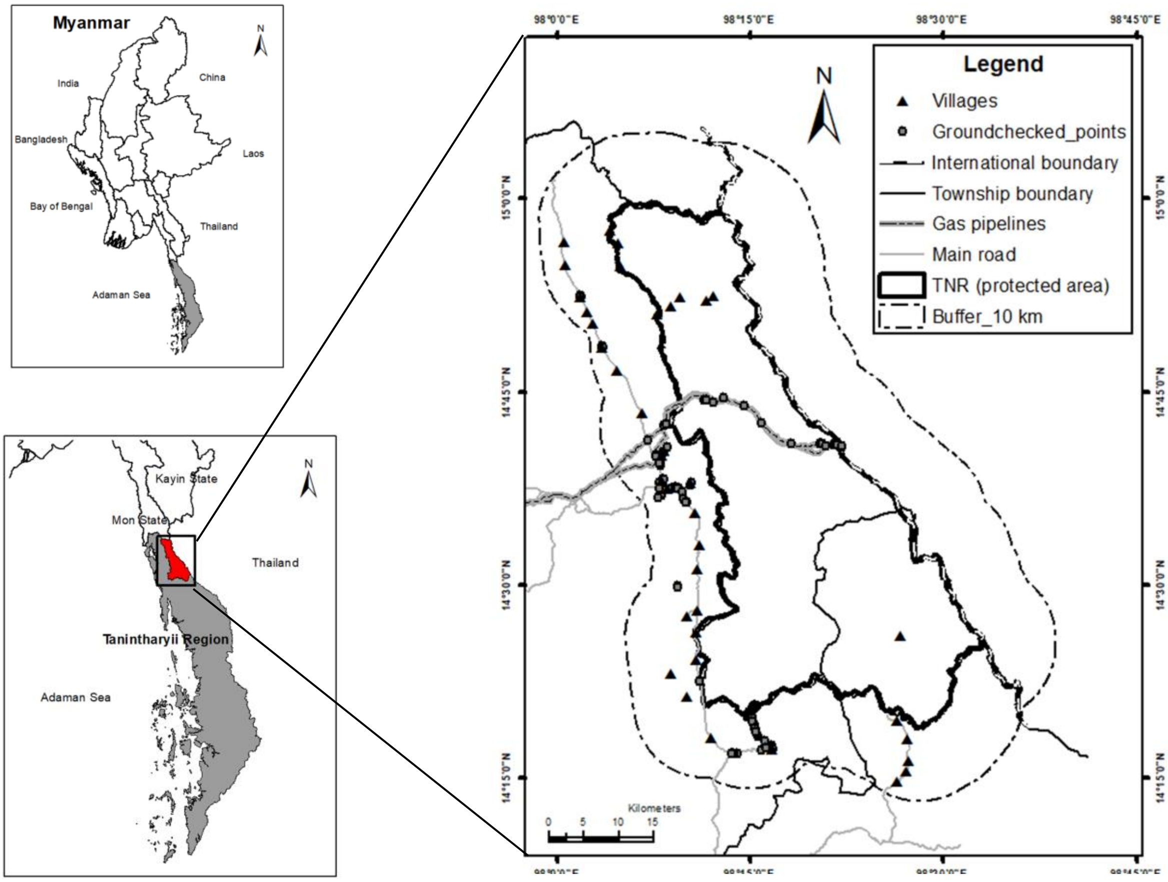


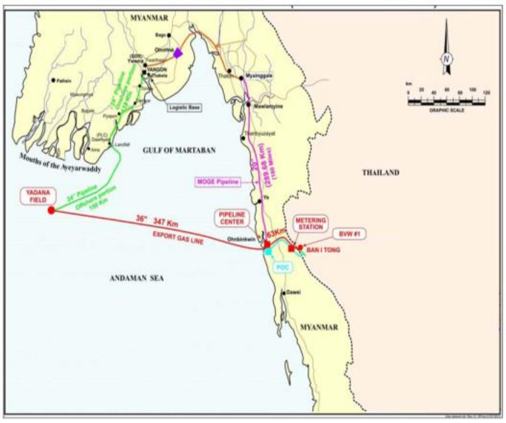
Figure 1. Location of study site, 10km buffer, three international gas pipelines and villages inside and surrounding TNR

TNR is almost covered by tropical rain forest in high elevation sites, mixed deciduous and bamboo forest in the lowlands. This Tropical rainforest is considered as the richest, oldest, most productive and most complex ecosystem on earth. It has 5 critically endangered species and 5 endangered species (Thein, 2007). Taninthayii Nature Reserve (TNR) is a biodiversity hotspot area, was comprised of three reserves, namely the eastern part, Kaleinaung, Heinze and Luwaing Reserve, were formerly demarcated in 1885, 1902 and 1932 under the management of Forest Department (FD).

It was changed and declared as a strictly natural protected area in 2005, namely, Taninthayii Nature Reserve (TNR), by the financial support of three International gas pipeline companies. These pipelines exploited and transported the gas from off-shore sea area to the Thailand site, shown in Fig. (2). It is a long-term project (2005-2028), as compensation financial support for impacts on biodiversity along the pipeline route because of pipelines passing across the center of these forest reserves.

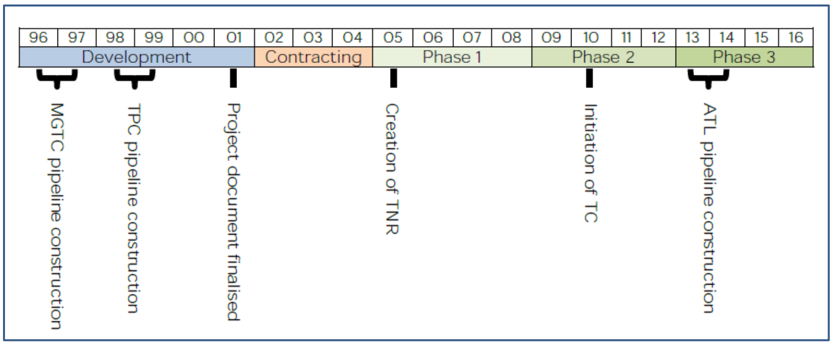
This is the first collaborative project between the Ministry of Natural Resources and Environmental Conservation, represented by Forest Department and two International Corporate (Corporate Social Responsibility) for conserving natural resources through the participation of local people. Each company supports $ 600,000 for four-year work plans (one phase). The budget was $1.2 million coming from each two companies in the first two phases (2005-2012). In 2012, Andaman Transportation Limited (ATL) representing the

Petroleum Authority of Thailand Exploration and Production International Limited (PTTEPI) a fellow Oil and Gas Company joined the consortium and have agreed to co-finance the project starting from the third phase (Saw Win & Maung Maung Pyone, 2012) as Fig. (3).



Source: (Yadana Consortium, 2012)

Figure 2. Map shows the one route of gas pipelines from the off-shore to TNR, finally to Thailand



Source: (Pollard, Hlaing, & Pilgrim, 2014)

Figure 3. TNR project development and project phase running structure

This is the first collaborative project between the Ministry of Natural Resources and Environmental Conservation, represented by Forest Department and two International Corporate (Corporate Social Responsibility) for conserving natural resources through the participation of local people. Each company supports $ 600,000 for four-year work plans (one phase). The budget was $1.2 million coming from each two companies in the first two phases (2005-2012). In 2012, Andaman Transportation Limited (ATL) representing the Petroleum Authority of Thailand Exploration and Production International Limited (PTTEPI) a fellow Oil and Gas Company joined the consortium and have agreed to co-finance the project starting from the third phase (Saw Win & Maung Maung Pyone, 2012).

There are over 34 villages, in the vicinity of TNR, in Fig. (1). There are over 30 villages within 10 km buffer and 11 villages on or inside TNR, the settled population is around 20845 (unpublished, Township Administration Office, 2017). There is a long history of settlement and four ethnic groups are now found settled. Namely, Dawei, Karen, Mon tribes and little Burma were mixed dwelling and migrated Karen and Mon tribes were dominant. Kayin (Karen) and Dawei tribes seem to be forerunners in the known history of settlement for more than 200 years. (unpublished, TNR operational management plan, 2017).

2.2 Data Sources

In this study, three pairs of bitemporal clear, cloud-free Landsat images were selected and checked many times to classify the study area: 1990 (Landsat 5 TM); 2006 (Landsat 5 TM) and 2017 (Landsat-8 OLI & TIRS) (Table.1 & 2). All satellite imageries were freely downloaded during the open season from the United States Geological Survey (Earth Explorer Website, https://earthexplorer.usgs.gov/). Landsat images 1990 and 2017 year were being able to acquire the cloud cover percentage less than 1, image quality is 9. During the 2006 period, Landsat image was found partial cloud, line stripes at the margin of images.

Table 1. Detailed list of applied data in this study

Type/ Resolution	Acquisition Date	Path/ Row	Data Sources	Reasons
Landsat-5 TM (30 meter)	Jan 29, 1990 Feb 23, 1990	131-050, 130-050	USGS Earth Explorer	Classification
Landsat-5 TM (30 meter)	Feb 10, 2006 Mar 07, 2006			
Landsat 8 OLI_TIRS (30 meter)	Jan 23, 2017 Feb 1st,2017			
Sentinel-2	Feb 9th,2017	3- Imagery	Earth Explorer	Validation for 2017 image classification
ALOS AVNIR-2	Dec 10th, 2008	ALAV2A 153323300	Myanmar Forest Department	Validation and supporting for 2006 image classification
ASTER Global DEM-2	October, 2011	3- Imagery	Earth Explorer	Checking the elevation
Topo and historical Maps (Secondary)	1945, 2010 & 2015		Myanmar Forest Department	Validation for three periods

2.3 Data collections

Key informant interviews

This study examined the village conditions and livelihood pattern in finding out the determinant factors on land use land cover change, focusing on forest cover change (namely deforestation). We conducted in-depth interviews with TNR project staff, few village heads, RECOFTC regional staff, related institutional local staff to understand the situation of local livelihood, any regional conflicts, difficulties and opportunities on forest monitoring. We explored various situations, and observations basically, the historical baseline information about the region.

Field verification

Field visit was carried out during the month of November and December 2017. We manipulated and collected GPS points (over 400) training samples, and recorded the photos attaching with GPS points. The ground checked points were conducted (1) within buffer zone and (2) into south part of TNR buffer and (3) alongside of maintenance road construction inside TNR (protected area) (Figure 1).

Table 2. Summary of ancillary datasets for LULC change analysis used in this study

Category	Data	Coverage	Use
Ancillary Data	Topographic/ UTM Maps	Taninthayii Nature Reserve topo map 14 sheets 1945	Use for accuracy assessment of 1990 image classification
	National forest report	Published by Forest Department, 1990-2015	To find out the historical and current issues on deforestation of TNR
	GIS shapefiles	TNR boundary, pipelines, road networks, township, Reserve forest, settlements	To access the roles of settlement expansion on the rate of deforestation in the protected area and surroundings
	GCPs Data	Ground control points (GCPs) during the field work	

Methodology Flowchart

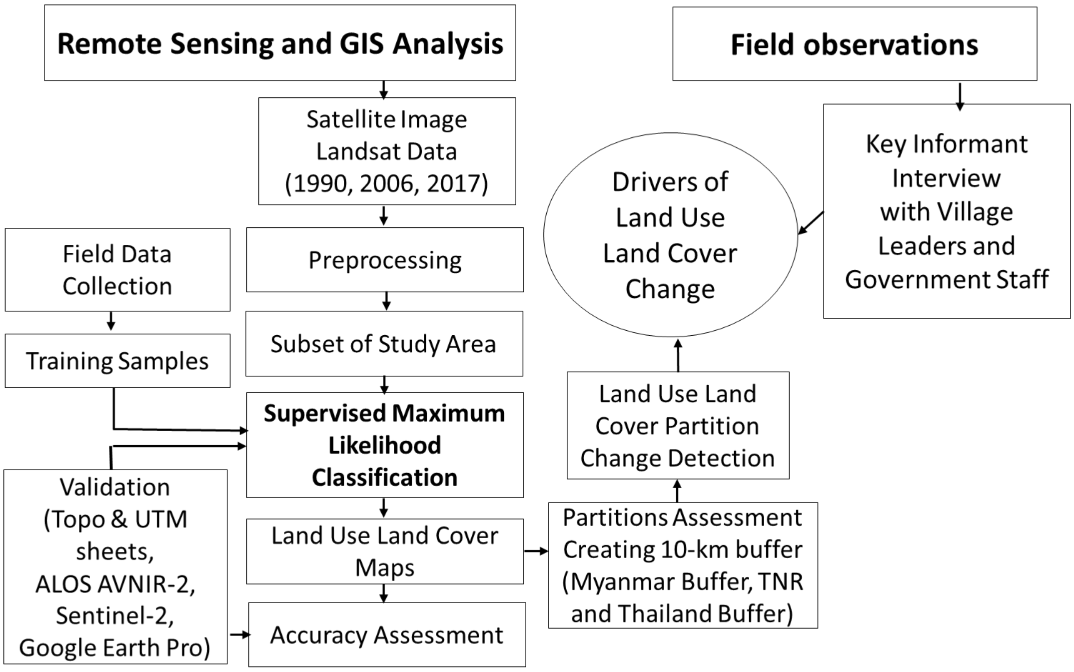


Figure 4 Methodology flowchart that was used in this study

Image preprocessing

After acquiring the satellite images of the study areas, preprocessing stage was applied to the research interest area by using the ENVI 5.5 software package. Radiometric calibration was done in FLAASH (First-line of sight of atmospheric analysis of hypercubes) function to correct the data for sensor irregularities and unwanted sensor or atmospheric noise, (Figure 4) Atmospheric corrections should be carefully carried out to remove the effects of the atmosphere on the reflectance values of images taken by satellite or airborne sensors (Resources, 1976). Then, pair of images were combined by using the mosaicked (georeferenced based or seamless/ feathering) function and were extracted the area of interest. Image enhancement is to improve the appearance of the imagery to assist in visual interpretation and classification (Resources, 1976).

Image classification

First, supervised maximum likelihood classification was applied to Landsat images acquired in 1990, 2006 and 2017, respectively (P Mondal, J Southworth (2009). Maximum Likelihood method is one of the most popular supervised classification method used with remote sensing image data, and Al-Ahmadi & Hames (2009) found that this method gave the best results among of four classification methods. For our objective, we created 10 km buffer outside of TNR (Mondal & Southworth, 2010; Nagendra et al., 2006) from TNR boundary, not only Myanmar side but also to Thailand side to spatially investigate the neighboring country effect to the Myanmar forest (Figure 1).

Definition of land use land cover classes

Table 3. Definition of land use land cover (LULC) categories with FAO definitions (FAO FRA, 2012)

	LULC class	**Description**
1	Dense Forest	>40% (canopy cover)
2	Open Forest	10-40% (canopy cover)
3	Other Wooded Land	< 10% (canopy cover)
4	Scrubland	lower shrubs, thatch
5	Grassland	Green and dry grass, Grazing land
6	Agricultural Land	Crop land, cultivable land, orchard, rubber/ oil palm plantation
7	Others	Settlement, bare land, rocky, transportation
8	Water	Permanent open water, streams, rivers, reservoirs

Post-classification

After classified thematic maps were developed, post-classification process was the last process in classification; (1) majority filter step for refining the thematic maps, (2) accuracy assessment; producer and user accuracy assessment, overall accuracy and kappa coefficient, was tested by methods of accuracy assessment commonly used the error matrix) by ArcMap (10.5) and Envi (5.3) software packages and Google Earth engine.

Partitioning the landscape

Furthermore, the management effectiveness of protected area was analyzed depending on different township landscape. Depending on eight LULC categories, TNR part is divided into three zones based on the two main reasons; gas pipelines across and township boundary divided to Yebyu and Dawei Township. Such landscape segmentation enables us to associate different zones of the landscape with measures of landscape deforestation and forest degradation, based on the identification of distinct patch features, we created the eight partition zones as shown in Figure 5.

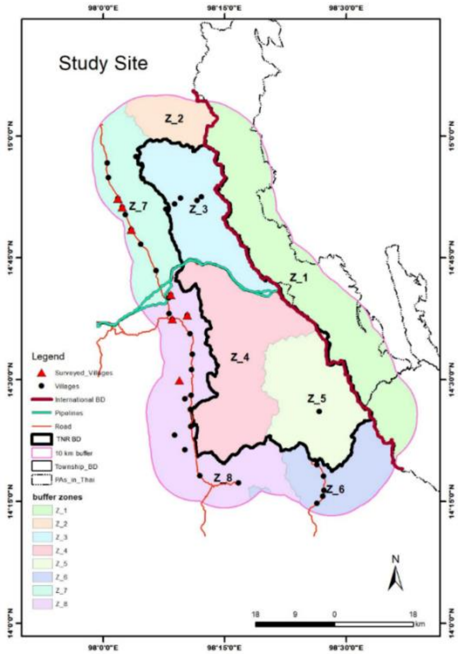


Figure 5. Map shows buffer 10 km, eight zones of landscape zonation, sample villages, gas pipelines, main road, international pipelines within Myanmar and protected areas inside Thailand.

Accuracy assessment

Accuracy assessment were executed for 1990, 2006 and 2017 LULC maps, respectively. A most common and typical method used to assess classification accuracy and overall accuracy is the use of an error matrix (Congalton & Green, 2009). The Kappa Coefficient was used, one of the most common means of expressing classification accuracy.

By using ArcMap (10.5) software tool, we employed the stratified random sampling points, considered based on the determined the number of land use land cover classes Eq. (1), percentage of dominant LULC category (UTSA, n.d.).

Based on multinomial probability theory:

$$\boxed{N = \frac{B\Pi_i(1-\Pi_i)}{b_i^2}} \qquad \text{Eq. (1)}$$

Is the proportion of a population in the i^{th} class out of k classes that has the proportion closest to 50%, b_i is the desired precision for this class, B is the upper $(\propto/k) * 100\, th$ percentile of the chi square x^2 $(x2)$ distribution with 1 degree of freedom, and k is the number of classes?

Deforestation and forest degradation rates

By using the standard formula, deforestation and forest degradation rates were calculated within TNR and Myanmar Buffer Zone. The following formula was used to estimate the rate of changes of forest cover between the period; 1990-2006, 2006-2017 and 1990-2017.

Deforestation = complete conversion of forest to non-forest

Gross forest degradation = closed forest to open forest (Uryu et al., 2008)

Forest cover and deforestation rates were calculated for the sub-time step datasets using the standardized approach proposed by Puyravaud, (2003).

$$Deforestation\ or\ Degradation\ rate\ per\ yr = \left\{\left[\frac{1}{time\ A2 - time\ A1}\right] * \log\left(\frac{A2}{A1}\right)\right\} * 100$$

Where:

A1 = Forest Area (Dense and Open forest) or Dense forest at beginning of time step

A2 = Forest Area (Dense and Open forest) or Dense forest at end of time step

Time A1 = Year and day count as digit number of beginning of time step

Time A2 = Year and day count as digit number of ends of time step

3. Results

Distribution of LULC inside TNR

There are numerous changes over time, and different location. The dominant land-use and land-cover for all three mapped years were forest including both, two forest categories (dense forest- 81% in 1990, 70% in 2006 and 58% in 2017) and open forest (8% in 1990, 15% in 2006 and 16% in 2017) within TNR (Table 7 and Figure 6). Agricultural land changed over time, firstly, existed stably at 2% in 1990, 1% in 2006 and dramatically increased up to 11% in 2017 (Table 7). Periodically, dense forests declined from 81% in 1990 to 70% in 2006 and seriously continued down to 58% in 2017. During the period of 27 years, dense forest moderately transformed to open forest and gradually transformed to degraded vegetation (combined with wooded land, scrub land and grassland) and agricultural land category (Figure 7).

In 1990 supervised classify image, there is less area of agriculture and settlement in the first period (Figure 6a). However, we found the forest degradation, named as open forest, wooded land and scrub land near the boundary of TNR. In the first period, open forest area became larger about two times from 8.11% in 1990 to 15.59% in 2006 (Table 7). Starting from 2006 thematic maps, the forest was suffered degraded surrounding the area of the pipelines route and also low elevation area (Figure 6b). Further, large area of wooded land was occurred increased nearby the settled villages, specially it is serious in the northern part and southern part of TNR. Gradually, wooded land moderately changed to the scrub land. The scrub can be observed in the north part of TNR in 2006, eventually, both categories like wooded land and scrubland transformed to the agricultural land near the villages and low elevation area in 2017 (Figure 6c).

Distribution of LULC within Myanmar buffer

Within 10-km buffer zone in Myanmar, the dominant categories were scrub land (45% in 1990) in the first period, before protection. Other side, wooded land (8% in 1990 up to 23% in 2006) were regained and scrub land decreased from 45% in 1990 to 25% in 2006 year, assumed by the activities of natural growth pattern. During the three periods, agricultural land existed 12% in the whole area of Myanmar Buffer (MB) in 1990 and slightly decreased to 10% in 2006, then, greatly rose again to 56% in 2017, given in Appendix, Table 7 and Figure 6 and 7.

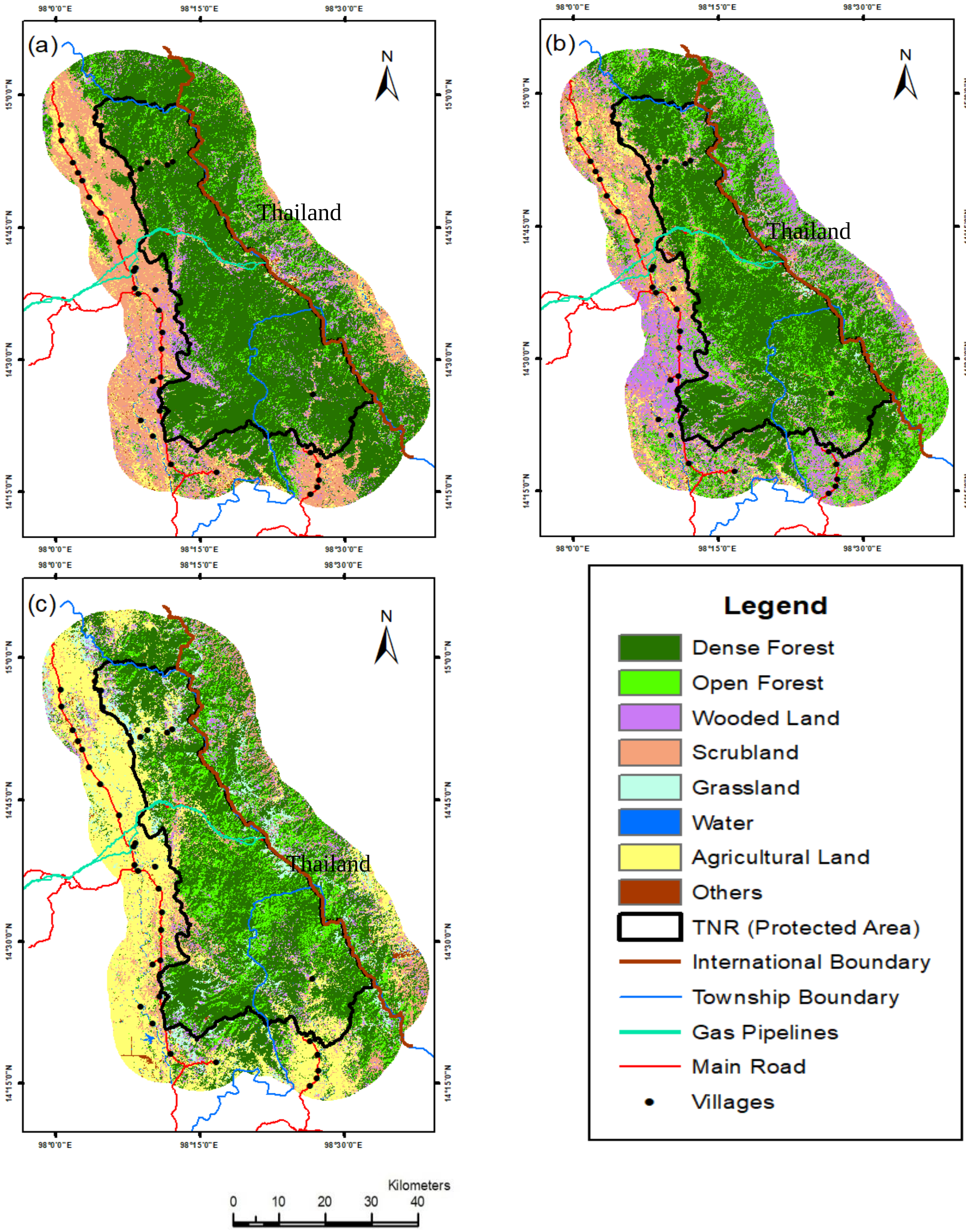


Figure 6. LULC Maps that was derived Landsat imageries within the protected area and 10 km buffer; (a) in 1990, (b) in 2006 and (c) in 2017

At first, agricultural land was mostly found in the northern part and southern part outside TNR, Figure (6a). The dominant category is scrub land in 1990, it might be resulted from shifting cultivation. It was replaced by the wooded land, as fallow land, due to the effect of natural regeneration pattern, distinctly, in south side of pipelines across that is hillside area.

According to 2017 LULC map, after a long time, most of the degraded vegetation was finally converted to the agricultural land within 10-km buffer inside Myanmar, particularly, along the main road and lowland area and other category like urban area was distinctly appeared in the southern part of TNR buffer, Figure 6c. Outside of TNR in former period, most area of northern part that was located inside Mon State was covered with dense forest. In addition, some parts of southern part in Buffer, that is falling into the different township called as Dawei Township, were still covered with forest. During the second period, there is seriously change of land use land cover in northern and southern part of buffer, located in Mon and Dawei area, Figure 6b. At the time of protection in 2006, land use land cover categories within Myanmar buffer zone were proportionally distributed from the largest percentage of each category (scrub- 25%, wooded land- 23%, dense forest- 21% and open forest- 17%), Appendix, Table 7. From 2017 classified results, we found that dense forest remained the stable conditions by expressing the area percentage (21% in 2006 and 20% in 2017), however, naturally preserved in different locations over time. Eventually, we observed that open forestand degraded vegetation, such as wooded land and scrubland slowly altered to agricultural land (land cover change) after being protected for 11 years, illustrated in Figure 6c.

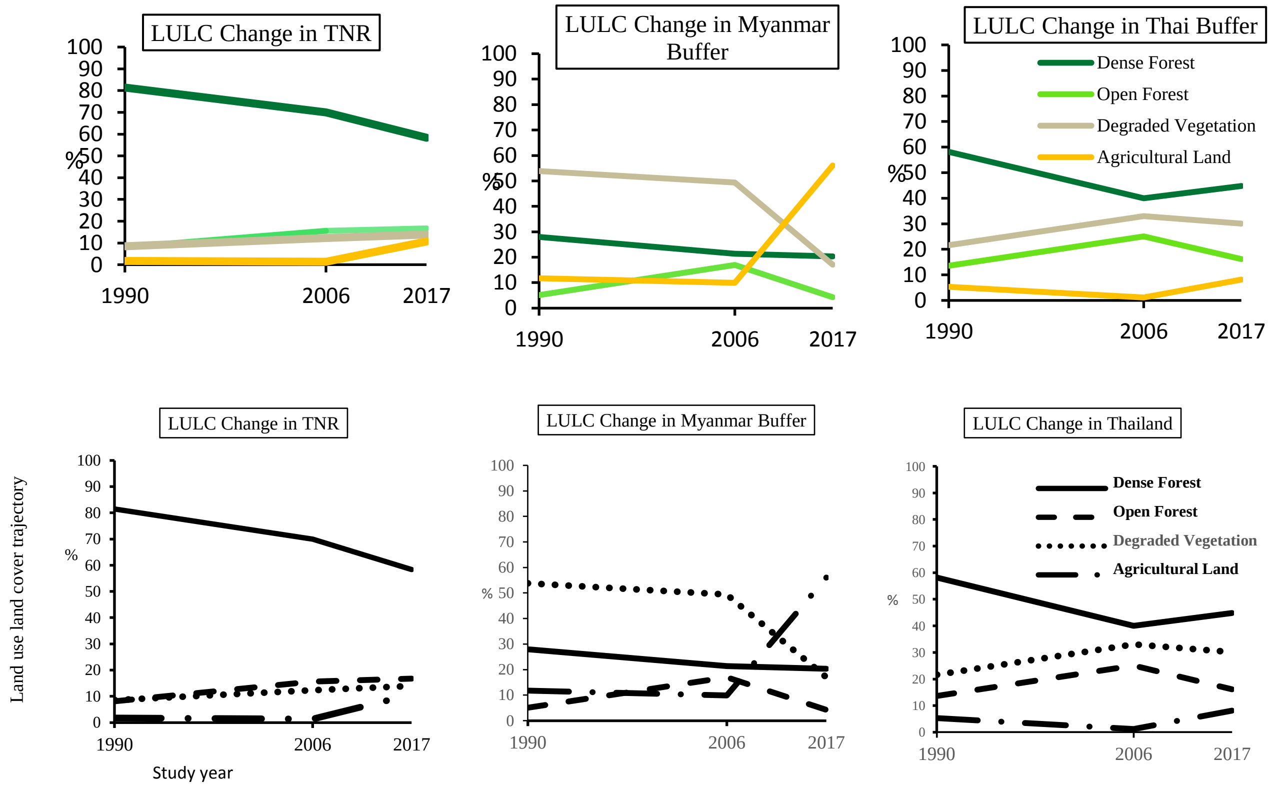


Figure7. Situations on LULC Change during the whole study period within the protected area and 10 km buffer; (a) in 1990, (b) in 2006 and (c) in 2017

Distribution of LULC inside Thailand buffer

In the first period, the dominant land use land cover categories were dense forest (58%), Table 7. Later, dense forest declined from 81% in 1990 to 40% in 2006, transformed to open forest was attained increasing from 14% in 1990 to 25% in 2006, as well, wooded land 10% in 1990 to 23% in 2006. In contrast, dense forests (40% in 2006 to 45% in 2017) were regained again from open forest and wooded land area. In agricultural land category, it was changed over time (5% in 1990, 1% in 2006 and 8% in 2017) and depending on different locations and situations, Figure 6 and Table 7.

Landscape partitions assessment

Zonal distributions of LULC inside TNR

Depending on eight LULC categories, TNR part is divided into three zones based on the two main reasons. Zone 3 (Z_3) is located at northern part of gas pipelines, the most deteriorated area. Zone 4 (Z_4) is a least disturbance area in the middle part of TNR or southern part of gas pipelines falling into the Yebyu Township. Zone 5 (Z_5) situated in south part of TNR, one location of human colonization and disturbed area.

We analyzed different patterns and the drivers of change inside the three zones between 1990, 2006 and 2017 year. Where the density of village settlements was greatest at the northeast to northwest sides, there was covered with less forest area in 2017. At the first analysis 1990, the dominant category was dense forest (37566 ha, 82% of Z_3), (53144 ha, 80% of Z_4) and (40437 ha, 83% of Z_5), respectively, there was no specific difference on the percentage of forest cover in three zones as explained in Appendix, Table 8 and 9.

In Zone_3, the net decrease of dense forest is greater in the second period (15%) than in the first period (during 11 years) (13%). Among of three zones, Zone_3 seriously suffered by the actual circumstances of not only dense forest deterioration (forest degradation) but also total forest area conversion (deforestation). In Zone_3, deforestation patterns (actual decrease, 18%) than forest degradation (actual decrease, 15%) mainly occurred after protection, just in case, natural vegetation was altered into another different category as agricultural land. It was remarkably experienced by the expansion of cultivable land (agricultural area) up to 17% in 2017 nearby Mon State, that occupied into different region and management system. Furthermore, we discovered open forest existence fluctuated from primary existence 10% in 1990, expanding 15% in 2006 and shrinkage again up to 12%, Table 9. The dense forest in Zone_3 among of three zones declined around 80% in 1990 to 54% in 2017, forest became degraded.

Like Zone_3 agricultural enlargement, there was similarly happened the same situation inside the place of Zone_5, that locates in the southern part of TNR. We obviously discovered the least deforested part is Zone_4 in the middle part of TNR, it experienced the less agricultural expansion 6% than 17% in Zone 3 and 11% in Zone 5. In contrast, forest degradation rate is the highest one than other two parts (open forest- 19% in Zone 4, 12% in Zone 3 and 18% in Zone 5). We found that forest degradation was critically experienced and steadily increased inside Zone_4 and Zone_5 than Zone_3 throughout 27 years.

Zonal distributions of LULC within Myanmar buffer zone

Figure 6 a, b, c. visualized land use land cover distribution over time. The individual classification from 1990 and 2017 depicted the impact that the 34 villages scattered in the different landscape. In all four zones, the area under dense forest has decreased substantially, while the area under non-forest categories has increased, indicating that the scrub areas over different landscape area regenerating to wooded land in some parts.

During 1990-2006 in Zone-2, forest cover was remarkably degraded to non-forest. Ordinarily, the dense forest cover of Zone_2 was considerably greatest percentage (14004 ha, 82%) among all four zones, followed by Zone _6 (14554 ha, 47%) and the least forest persistence occurred in Zone_7 (5891 ha, 13%) and Zone_8 (12124 ha, 17%) in 1990, Table 8 and 9 in Appendix. According to the 1990 classified results, the scrub land, that seems from the results of shifting cultivation and the fallow land that was abandoned after practicing the shifting cultivation, was found as the most dominant category inside Zone_7 and Zone_8 at the first period.

In Zone 7, the dominant category in 1990 was indicated as scrubland (28559 ha, 63%), followed by agricultural land (7412 ha, 16%), dense forest (5891 ha, 13%), explained as Appendix, Table 8 and 9. However, there is a substantial decrease in the area of scrubland (20066 ha, 44% in 2006), partially transformed to agricultural land as a dominant category (became as 74% in 2017). At the same time, in Zone 8, the dominant land cover category was occupied as scrubland (36896 ha, 51%), followed by agricultural land (9883 ha, 14%) and wooded land (9796 ha, 13%) in 1990. Later, there is certainly a substantial change in the number of LULC categories, wooded land was resulted as a most influenced category (24796 ha, 34%), and scrubland decreased to (16903 ha, 23%) in 2006, and then agricultural land was visible as a dominant category (43433 ha, 60%), followed by dense forest (11394 ha, 16%) and scrubland (7034 ha, 10%) in 2017.

Deforestation and forest degradation rates

Firstly, when we look up the calculated results on protected area as shown in Table 5, the deforestation rate (-0.52%) after protection was greater than the rate (-0.12) before protection, shown in Table 5. Similarly, the forest degradation rate is steadily higher than the deforestation rate at the time of before and after protected situation both. Outside TNR, within Myanmar buffer area, we observed the condition of reforestation, that means natural regrowth pattern, (0.4%) was attained during the first period. The tremendous forest clearing to another land use land cover, that means deforestation (-1.75%) was found during the second period (2006-2017), while the protected area was being established and gas pipelines project initiated.

During 27 years, 1990-2017, the mean annual deforestation rate (-0.28) experienced lower than the forest degradation rate (-0.54), (Table 5). Throughout the time of 27 years, the mean annual deforestation rate was higher within buffer than inside TNR, nevertheless, the mean annual forest degraded rate inside TNR was greater than outside TNR, protected area.

Comparing the areas outside and inside the protected area, outside TNR experienced the greater forest degradation in the first period, moreover, highest deforestation rate (-1.75) was occurred during second period.

Table 5. Rates of deforestation and forest degradation inside protected area (TNR) and within their 10 km buffer of Myanmar during the study period

Location	Study period	Deforestation rate per yr^{-1}	Degradation rate yr^{-1}
1. TNR, protected area	1990-2006	-0.12	-0.41
	2006-2017	-0.52	-0.72
	1990-2017	-0.28	-0.54
2. Myanmar Buffer	1990-2006	0.40	-0.73
	2006-2017	-1.75	-0.19
	1990-2017	-0.47	-0.51

Accuracy assessment

Appendices A, Table 19, 20 and 21 show error matrices based on the supervised maximum likelihood classification results of the years 1990 to 2017. The overall accuracy of the TNR LULC 1990, 2006 and 2017 maps presented 82.6%, 85.2% and 88.2% and Kappa coefficient of classification image dated 2017 was 84.3%, Table 6. It is high compare to other images of 2006 and 2017 were 80.1%, 74.8%, respectively, as shown in Appendix Table 10, 11, 12.

Table 6. Summary of Landsat classification accuracies (%) for 1990, 2006 and 2017

Land use land cover class	1990		2006		2017	
	Producer's	User's	Producer's	User's	Producer's	User's
Dense Forest	98.9	86.5	97.6	89.9	98.5	91.1
Open Forest	43.8	78.0	76.5	78.2	71.4	95.2
Other Wooded Land	69.7	83.6	78.7	84.0	51.5	85.0
Scrub	93.2	79.0	89.2	76.3	80.9	79.2
Grassland	80.0	80.0	100.0	90.9	95.5	87.5
Water	83.3	50.0	100.0	100.0	100.0	40.0
Agriculture	51.5	74.5	52.9	94.7	95.7	87.3
Others	80.0	80.0	77.8	70.0	100.0	70.0
Overall accuracy	82.6		85.2		88.2	
Kappa statistic	74.8		80.2		84.3	

4. Discussion

Classification accuracy

We acquired the high accuracy of classification image in 2017 with the aid of ground truth points and various ancillary data. Particularly, the Landsat_5TM images 1990 were not vivid to clarify the determined LULC categories with the lack of reliable historical data. Hence, during the field survey, we observed that the areas classified as shrub also included young rubber plantation and open forest also included old rubber, oil palm plantations in 2006 LULC map. It is because the crown patterns of rubber plantation and shrub forest were similar to each other and sometimes they are mixed spectral reflectance with each other (Like, Boundeth & et al, 2012).

Land Use Land Cover (LULC) change inside TNR

In this study, the results revealed that there is a considerable change in forest cover at a faster pace. Different situations that influenced on land use land cover dynamics were occurred on the location. Dense forest was potentially fragmented as the form of open forest, that was legally and illegally logged during the time of 27 years.

In 1988, Ministry of forestry created income from the natural resource extraction, for granting the logging activities to the national and international private companies both. They granted contracts to foreign companies, Thailand companies. It improved access to virtually undisturbed forest areas in the Taninthayii Mountain Range running along the Myanmar-Thai border, (Taninthayi Nature Reserve Project, 2013). The resulting regular transports of logs to Thailand provided opportunities legally and illegal trade in wildlife and forestry products as well. However, in 1996, the Myanmar Government ceased allowing Thai logging companies to continue operation in Myanmar due to gross violations by clear-cutting and logging outside designated areas as well as exporting more timber than was specified (Seatec International, 1999).

According to the Forest Law 17 (1992), it was stated that forest products may be extracted for domestic or agricultural or piscatorial use and not on a commercial scale by local people. Normally, local people near TNR extract small-sized timber for house buildings and furniture making. Local people now use chainsaws not only for felling and logging but also for sawing timber (Tin Swe, 2008). According to the key informant interview, FD staff could not terminate the commercial scale of illegal logging that was generated by the intruders, outsiders and settled indigenous armed society.

At the location of high elevation and deep slope, dense forest distinctly remained, and natural regrowth was excellent. In low elevation, forests are mostly degraded and transformed to another land use. Slope has been a distinct factor affecting the spatial pattern of village expansion. Generally, people prefer to live on flat or gentle terrain (Estoque & Murayama, 2011).

Owing to the fact that the number of 9 villages colonized by Mon indigenous people, named as ‘Mon Pyi Thit’ area. Since 1995, these villages are located inside northern TNR. As a result, the obvious settlement of 9 villages on the periphery utilize forest products for substantial use and orchard establishment inside TNR, which owing to their greater human populations (Taninthayi Nature Reserve Project, 2013).

On the other side, the detrimental impacts on the forest, particularly forest degradation was more severe at the middle part of protected area. There is still evidence of shifting cultivations/ orchards particularly in the northern and southern parts of TNR up to 2010 (Taninthayii Nature Reserve Project, 2015). Beside this, we noticed from field observations that these ethnic villagers’ practice as orchard-based shifting cultivation and extraction of forest resources; felling timber and NTFP for substantial use and commercial selling.

Further, we noticed from key informant interviews and observation that ethnic people mainly operated the logging activities with some buffaloes and using river route for carrying the drifted timber. In the PA patrolling case, when the project staff and forest department investigated any sign or information relevance with the prohibited timber extraction, encroachment, in-migration activities, they cannot fully control or halt such kind of activities because some of them who are local forces firmly hold the guns. In the case of arresting the felled logs or anybody, forest department staff are unexpectedly being suffered from the attack of the illegal logging association due to guns-holding of two ethnic groups and human dwelling inside the PA. Hence, there still exists minor conflicts that come from various kinds of impacts between conservation efforts of forest department and resource extraction and dependence of ethnic armed society on forest.

In the interior part of TNR, driving forces leading to deterioration of natural forests were non-identical in southern part and northern part due to individual preferences and customs of ethnicities. Northern part was mostly suffered by deforestation, for example, agricultural expansion. Middle part was damaged by the gas pipelines construction and agricultural encroachment near TNR boundary due to unclear boundary and less knowledge of local people concerned with TNR boundary demarcation. Ethnicity in TNR south part rely on forest resources, both agriculture and illegal logging because timber extraction is the quickest way for these communities to realize rapid profits, like (Myint Aung, 2007).

Deforestation and forest degradation within TNR and Buffer

One important finding of this study was that, within PA and their surroundings, they similarly experienced situation of deforestation and forest degradation on different spatial and temporal scale. According to the calculated results, deforestation rate outside TNR was remarkably higher than any rate than in the TNR interior. Demarcation as protected area can lessen the conversion of forest to another land use. However, we discovered the appearance of forest deterioration, called forest degradation. It was continuously increased from (-0.41) to (-0.72) in the second period even though it was conserved and monitored as a naturally protected area with pipelines project's financial support. Figure shows the comparison of annual deforestation rate of TNR and other studies: PMP; Popa Mountain Park, Bago Mountain and FAO 2015 report. In the comparison of both two rates, forest degradation rates were greater than deforestation pattern at any time, similar these studies in Myanmar Popa Mountain Park (PMP) (Htun et al., 2009) and Bago Mountain area (Mon et al., 2010).

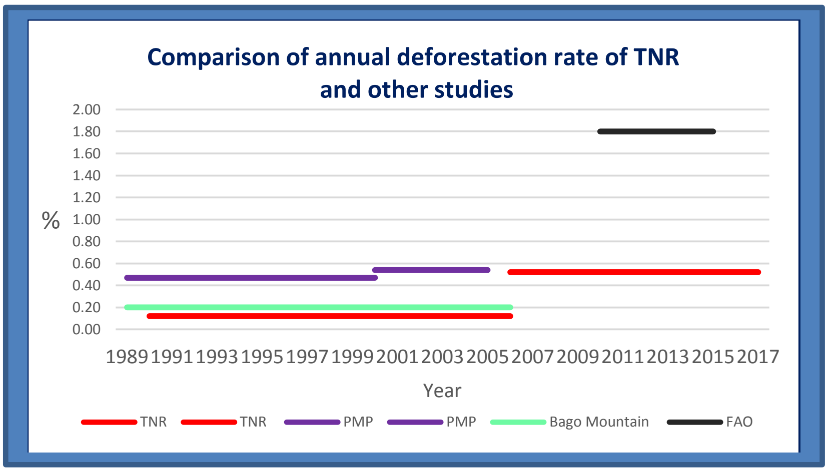


Figure 8. Comparison of annual deforestation rate of TNR and other studies: PMP; Popa Mountain Park (Htun et al., 2009), Bago Mountain (Mon et al., 2010) and FAO 2015 report estimated for Myanmar

This study pointed out that after being protection, the rates of deforestation (-0.52) and forest degradation (-0.72) was greater than any rate (-0.12) and (-0.41) before being notified as a protected area. Dense forests were deteriorated and changed to open forests due to the surrounding human disturbances, subsequently, transformed to non-forest categories with the lack of strict conservation. At last, non-forest categories periodically changed each other over time. This finding approved that the land use land cover change was highly experienced at the level of the low elevation alongside the main road, near the river and surrounding the human settlement area.

During the time of 27 years, dense forest gradually declined, and large area of open forest gained. Non-forest area became greater from time to time, particularly, agricultural land expanded to a greater amount. The three major threats bringing about land use land cover change are (1) commercial illegal logging, (2) huge expansion of agricultural land by the activities of two ethnic armed groups, and (3) pipelines construction. In local circumstances, local people hugely practiced in shifting cultivation before TNR project initiating.

Forest cover could not be maintained at a stable condition. Hence, resource management strategies of TNR project monitored and managed by FD is still weak and less effective on resource conservation. The Forest Department should concentrate its eco-development activities on the villages located outside the park, justifying this focus by stating that ‘‘in the villages inside the Protected Area, no permanent development works will be taken as they are to be relocated’’. Eco-development activities that allow these communities to generate alternate sources of income could be very useful in reducing the levels of illegal harvesting (Nagendra et al., 2006).

When we conserve and manage the natural forest, we should carefully consider the social, economic and political factors of this region. This area is unlike another study area, there are many interesting things and unique characteristics to deeply understand, heterogenous ethnicity, minor conflicts hard to handle by national government. A focus on institutions/ ethnic armed groups rather than ‘community’ is likely to be more fruitful for those interested in community-based natural resource management (AGRAWAL et al., 1999), and should promote not only the extension program but also the budget support by national/regional government and incorporation with the NGO, INGO projects like effective and well-planned long-term project.

5. Conclusion and Recommendations

This study revealed spatial and temporal change of land use land cover, comparison analysis inside the protected area and their surroundings, Myanmar buffer and Thailand buffer. Remote sensing and GIS techniques were both applied to clarify land use land cover change, focusing on forest loss, moreover, field observations data were integrated to investigate the current and historical LULC information. By creating 10-km buffer starting from the boundary of protected area, we analyzed the management effectiveness of protected area in the comparison of forest cover change inside and outside protected area in Taninthayii

Region, Southern Myanmar. The overall results illustrate the complex interactions between social, economic and political situations, particularly, when ethnic heterogeneity is considered.

Inside TNR, initiating the eco-development project, establishment of village-owned tree plantations and forming as eco-tourism site should be prioritized. The Forest Department concentrates its eco-development activities on the villages located outside the park, justifying this focus by stating that ‘‘in the villages inside the Protected Area, no permanent development works will be taken as they are to be relocated’’. Eco-development activities that allow these communities to generate alternate sources of income could be very useful in reducing the levels of illegal harvesting (Nagendra et al., 2006). Moreover, for local livelihood improvement outside TNR, more firms and similar long-term projects by the support of national and international budget should be called up by the national government that makes enrich the local products to support off-farm employment opportunities. Moreover, they should do improve durable and best access the road network and electricity, similarly, forest plantations to the Kayin villages.

Acknowledgements

I extend my heartfelt thanks to all the contributors of this research conduct for making this endeavor possible. There is a large number of people to thank for their help and kind support on this research work. Firstly, I would especially like to thank sponsored and/or financially supported Asian Development Bank- Japanese Scholarship Program (ADB-JSP). I want to express my gratitude to my academic advisors, particularly, Prof. Mamoru KANZAKI, for his close supervision and scientific guidance, and Ministry of Natural Resources and Environmental Conservation for granting this opportunity to study in Kyoto University, Japan. I would like to extend my sincere thanks to USGS Earth Explorer, for releasing the free permission to acquire the various kinds of Satellite Imagery in anytime. Along the way, I also gratefully acknowledge all my laboratory friends and study community who inspired and encouraged me in the Laboratory of Forest Resources & Society and Tropical Forest Resources & Environments, Kyoto University. My heartfelt thanks are extended to the staff of Head quarter office from Forest Department (FD), Tanintharyii Nature Reserve Project, filed staff from Yephyu Township and Dawei Division FD, moreover, wishing to extend to the cooperating local villagers for their earnest help, enthusiastically participation and generous care in the field work and data collection.

References

Achard et al. (2002). Determination of deforestation rates of the world ’ s humid tropical forests. *Science*, *297*(August), 999–1002. https://doi.org/10.1126/science.1070656

AGRAWAL et al. (1999). Enchantment and disenchantment: The role of community in natural resource conservation. *World Development*, *27*(4), 629–649. https://doi.org/10.1016/S0305-750X(98)00161-2

Al-Ahmadi, F. S., & Hames, A. S. (2009). Comparison of four classification methods to extract land use and land cover from raw satellite images for some remote arid areas, Kingdom of Saudi Arabia. *Journal of King Abdulaziz University, Earth Sciences*, *20*(1), 167–191. https://doi.org/10.4197/Ear.20-1.9

Bahuguna, V. K. (2000). Forests in the Economy of the Rural Poor: An Estimation of the Dependency Level. *AMBIO: A Journal of the Human Environment*, *29*(3), 126–129. https://doi.org/10.1579/0044-7447-29.3.126

Boundeth, S., & et al. (2012). Land Use Change and Its Determinant Factors in Northern Laos: Spatial and Socio-economic Analysis. *Journal of Agricultural Science*, *4*(12), 190–204. https://doi.org/10.5539/jas.v4n12p190

Congalton, R. G., & Green, K. (2009). *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. *The Photogrammetric Record* (Vol. 2). https://doi.org/10.1111/j.1477-9730.2010.00574_2.x

Dinerstein et al. (1993). Beyond “Hotspots”: How to Prioritize Investments to Conserve Biodiversity in the Indo-Pacific Region. *Conservation Biology*, *7*(1), 53–65. https://doi.org/https://doi.org/10.1046/j.1523-1739.1993.07010053.x

Djomo Nana, E., & Ngameni Tchamadeu, N. (2014). Socio-Economic impacts of protected areas on people living close to the Mount Cameroon National Park. *Parks*, *20*(2), 129–137. https://doi.org/10.2305/IUCN.CH.2014.PARKS-20-2.EDN.en

Estoque, R. C., & Murayama, Y. (2011). Spatio-temporal urban land use/cover change analysis in a hill station: The case of Baguio city, Philippines. *Procedia - Social and Behavioral Sciences*, *21*, 326–335. https://doi.org/10.1016/j.sbspro.2011.07.016

FAO. (2006). *Global Forest Resources Assessment 2005: Progress towards sustainable forest management*. *FAO Forestry Paper 147*. https://doi.org/ISBN 92-5-105481-9

FAO. (2010). Global Forest Resources Assessment 2010. *FAO Forestry Paper*, *163*, 350 pp. https://doi.org/ISBN 978-92-5-106654-6

FAO FRA. (2012). Forest Resources Assessment 2015: Terms and Definitions. *FAO Report*,

36. Retrieved from http://www.fao.org/docrep/017/ap862e/ap862e00.pdf

Fox et al. (2009). Policies, political-economy, and Swidden in southeast asia. *Human Ecology*, *37*(3), 305–322. https://doi.org/10.1007/s10745-009-9240-7

Hadley, M. and Lanly, J. P. (1982). Tropical forest ecosystems: identifying differences, seeing similaritie. *Nature and Resources*, *19*, 2–19.

Htun et al. (2009). Deforestation and forest degradation as measures of Popa Mountain Park (Myanmar) effectiveness. *Environmental Conservation*, *36*(3), 218–224. https://doi.org/10.1017/S0376892909990415

Kim, D. H., Sexton, J. O., Noojipady, P., Huang, C., Anand, A., Channan, S., … Townshend, J. R. (2014). Global, Landsat-based forest-cover change from 1990 to 2000. *Remote Sensing of Environment*, *155*, 178–193. https://doi.org/10.1016/j.rse.2014.08.017

Lwin et al. (1990). *Wildlife Conservation in Myanmar*. Yangon, Myanmar.

Manivong, V., & Cramb, R. A. (2008). Economics of smallholder rubber expansion in Northern Laos. *Agroforestry Systems*, *74*(2), 113–125. https://doi.org/10.1007/s10457-008-9136-3

Melillo et al. (1985). A Comparison of Two Recent Estimates of Disturbance in Tropical Forests. *Environmental Conservation*, *12*(1), 37–40. Retrieved from https://doi.org/10.1017/S0376892900015137

Molofsky et al. (1985). Comparison of tropical forest surveys. United States: N. p., Web., 66 pp.

Mon et al. (2010). MonitoringDeforestationand Forest Degradation the Bago Mountain Area,Myanmar using FCD Mapper. *Japan Society Japan Society of Forest Planning*, *15*, 63–72. Retrieved from https://www.jstage.jst.go.jp/article/jfp/15/2/15_KJ00007700323/_pdf/-char/en

Mondal, P., & Southworth, J. (2010). Protection vs. commercial management: Spatial and temporal analysis of land cover changes in the tropical forests of Central India. *Forest Ecology and Management*, *259*(5), 1009–1017. https://doi.org/10.1016/j.foreco.2009.12.007

Mukul, S. A., & Herbohn, J. (2016). The impacts of shifting cultivation on secondary forests dynamics in tropics: A synthesis of the key findings and spatio temporal distribution of research. *Environmental Science and Policy*, *55*, 167–177. https://doi.org/10.1016/j.envsci.2015.10.005

Myers, N. (1980). Conservation of tropical miost forests. *(Report to National Academy of*

Sciences). National Research Council, Washington DC, 205 pp.

Myers, N. (1985). Tropical deforestation and species extinctions: : the latest news. *Futures*, *17*, 451–463.

Myint Aung, U. (2007). Policy and practice in Myanmar's protected area system. *Journal of Environmental Management*, *84*(2), 188–203. https://doi.org/10.1016/j.jenvman.2006.05.016

Nagendra et al. (2006). People within parks - Forest villages, land-cover change and landscape fragmentation in the Tadoba Andhari Tiger Reserve, India. *Applied Geography*, *26*(2), 96–112. https://doi.org/10.1016/j.apgeog.2005.11.002

Naughton-Treves et al. (2005). THE ROLE OF PROTECTED AREAS IN CONSERVING BIODIVERSITY AND SUSTAINING LOCAL LIVELIHOODS. *Herpetological Conservation and Biology*, *30*(1), 219–252. https://doi.org/10.1146/annurev.energy.30.050504.164507

Pollard, E. H. B., Hlaing, S. W., & Pilgrim, J. D. (2014). *Review of the Taninthayi Nature Reserve Project as a conservation model in Myanmar* (Vol. 44).

Puyravaud, J. P. (2003). Standardizing the calculation of the annual rate of deforestation. *Forest Ecology and Management*, *177*(1–3), 593–596. https://doi.org/10.1016/S0378-1127(02)00335-3

Resources, N. (1976). Fundamentals of remote sensing. *Resources Policy*, *2*(1), 65. https://doi.org/10.1016/0301-4207(76)90065-9

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., … Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *Science*, *287*(5459), 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Saw Win & Maung Maung Pyone. (2012). *FINAL REPORT- TANINTHAYI NATURE RESERVE, unpublished report*. Yangon, Myanmar.

Snyman, S. (2012). THE IMPACT OF LAND MANAGEMENT SYSTEMS ON COMMUNITY ATTITUDES TOWARDS TOURISM AND CONSERVATION IN SIX SOUTH AFRICAN COUNTRIES. *Koedoe*, *18*(November), 1–12. Retrieved from http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0075-64582014000200004&lang=es

Taninthayi Nature Reserve Project. (2013). *Taninthayi Nature Reserve Operational Management Plan, Departmental Report*. Yangon, Myanmar.

Taninthayii Nature Reserve Project. (2015). *Taninthayi Nature Reserve Operational*

Management Plan (2013-2014 ~ 2016-2017), unpublished report. Yangon, Myanmar.

Thein, H. M. (2007). *Report on flora survey in Taninthayi Nature Reserve, Myanmar. Forest Department, Ministry of Forestry. Union of Myanmar, unpublished report*. Yangon, Myanmar.

Tin Swe. (2008). *Community Forestry for Taninthayii Nature Reserve Project*. Yangon, Myanmar.

UN FAO. (2015). *Global Forest Resources Assessment 2015 - Desk reference*. Retrieved from http://www.fao.org/3/a-i4808e.pdf

Uryu, Y., Mott, C., Foead, N., Yulianto, K., Budiman, A., Takakai, F., … Stüwe, M. (2008). Deforestation, Forest Degradation, Biodiversity Loss and CO2 Emissions in Riau, Sumatra, Indonesia. *WWF Indonesia Technical Report*, 1–80. Retrieved from http://assets.panda.org/downloads/riau_co2_report__wwf_id_27feb08_en_lr_.pdf

UTSA. (n.d.). Classification Accuracy Assessment. Retrieved July 20, 2018, from www.utsa.edu/lrsg/teaching/ees5083/l9-classaccuracy.pdf

van Vliet et al. (2012). Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: a global assessment. *Global Environmental Change, 22*, 418–429. https://doi.org/10.1016/j.gloenvcha.2011.10.009

Watson et al. (2014). The performance and potential of protected areas. *Nature, 515*(7525), 67–73. https://doi.org/10.1038/nature13947

Yadana Consortium. (2012). *Annual Report 2012 Yadana Socio-Economic Program, unpublished report*. Yangon, Myanmar. Retrieved from Pipelines

Appendices: Results about LULC Change during the three periods

Table 7. Comparison of LULC change in 1990, 2006 and 2017 year by three zones (TNR, Myanmar Buffer and Thailand Buffer) described as (ha and %)

Year		Dense Forest	Open Forest	Wooded Land	Scrubland	Grassland	Water	Agricultural Land	Others
1990	TNR (ha)	131147	13061	8328	5197	243	62	2866	187
	%	81.41	8.11	5.17	3.23	0.15	0.04	1.78	0.12
	Myanmar Buffer (ha)	46573	8433	14032	75387	267	755	19526	1625
	%	27.96	5.06	8.42	45.25	0.16	0.45	11.72	0.98
	Thai Buffer (ha)	53020	12394	9364	10039	256	712	4811	557
	%	58.17	13.60	10.27	11.01	0.28	0.78	5.28	0.61
2006	TNR (ha)	112751	25108	9178	7666	2954	196	2223	1011
	%	69.99	15.59	5.70	4.76	1.83	0.12	1.38	0.63
	Myanmar Buffer (ha)	35605	28253	38954	41524	1741	887	16528	3004
	%	21.38	16.97	23.40	24.94	1.05	0.53	9.93	1.80
	Thai Buffer (ha)	36443	22854	20771	7736	1564	176	1074	505
	%	39.99	25.08	22.79	8.49	1.72	0.19	1.18	0.55
2017	TNR (ha)	93989	26910	7377	5097	9964	240	17163	349
	%	58.35	16.71	4.58	3.16	6.19	0.15	10.65	0.22
	Myanmar Buffer (ha)	33906	7126	7705	11167	9536	1389	93416	2329
	%	20.35	4.28	4.63	6.70	5.72	0.83	56.08	1.40
	Thai Buffer (ha)	40816	14723	8069	11369	7987	153	7409	605
	%	44.79	16.16	8.85	12.48	8.76	0.17	8.13	0.66

Table 8. Comparison of LULC change in 1990, 2006 and 2017 year by 8 partitions assessment described as (ha)

Year	**LULC Category**	**Landscape zones**							
		Zone_1	**Zone_2**	**Zone_3**	**Zone_4**	**Zone_5**	**Zone_6**	**Zone_7**	**Zone_8**
1990	Dense Forest	53020	14004	37566	53144	40437	14554	5891	12124
	Open Forest	12394	1743	4656	4455	3950	2035	2361	2294
	Wooded Land	9364	982	1169	4935	2224	2188	1065	9796
	Scrubland	10039	176	1906	2190	1100	9756	28559	36896
	Grassland	256	9	52	165	26	25	63	170
	Water	712	3	19	10	34	106	111	536
	Agricultural Land	4811	142	662	1455	749	2090	7412	9883
	Others	557	1	14	141	32	210	129	1284
2006	Dense Forest	36443	11491	31539	47066	34146	9632	3540	10941
	Open Forest	22854	3579	6967	9709	8432	8840	4570	11264
	Wooded Land	20771	885	2407	4429	2343	7180	6092	24796
	Scrubland	7736	655	2823	3189	1654	3900	20066	16903
	Grassland	1564	153	680	1075	1200	318	546	724
	Water	176	7	37	80	80	106	89	685
	Agricultural Land	1074	194	1289	547	387	694	9488	6152
	Others	505	72	299	402	309	296	1157	1478
2017	Dense Forest	40816	10592	24706	40228	29055	9609	2311	11394
	Open Forest	14723	1140	5523	12414	8973	3306	392	2289
	Wooded Land	8069	884	2129	2698	2550	1826	1837	3159
	Scrubland	11369	308	1279	3020	798	1982	1843	7034
	Grassland	7987	601	4389	3880	1694	1324	4186	3425
	Water	153	19	102	69	69	153	169	1048
	Agricultural Land	7409	3438	7715	4064	5384	12618	33927	43433
	Others	605	80	199	124	26	141	918	1191

Table 9. Comparison of Land Use Land Cover Change for 1990, 2006 and 2017 year by 8 partitions assessment, described as (%)

Year	LULC Category	Landscape zone							
		Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8
1990	Dense Forest	58.17	82.08	81.59	79.92	83.29	47	12.92	16.61
	Open Forest	13.6	10.22	10.11	6.7	8.14	6.57	5.18	3.14
	Other Wooded Land	10.27	5.76	2.54	7.42	4.58	7.07	2.34	13.42
	Scrubland	11.01	1.03	4.14	3.29	2.27	31.51	62.64	50.55
	Grassland	0.28	0.05	0.11	0.25	0.05	0.08	0.14	0.23
	Water	0.78	0.01	0.04	0.01	0.07	0.34	0.24	0.73
	Agricultural Land	5.28	0.83	1.44	2.19	1.54	6.75	16.26	13.54
	Others	0.61	0.01	0.03	0.21	0.06	0.68	0.28	1.76
2006	Dense Forest	39.99	67.45	68.5	70.78	70.33	31.1	7.77	15
	Open Forest	25.08	21.01	15.13	14.6	17.37	28.55	10.03	15.44
	Other Wooded Land	22.79	5.2	5.23	6.66	4.83	23.19	13.37	33.99
	Scrubland	8.49	3.85	6.13	4.8	3.41	12.59	44.05	23.17
	Grassland	1.72	0.9	1.48	1.62	2.47	1.03	1.2	0.99
	Water	0.19	0.04	0.08	0.12	0.16	0.34	0.2	0.94
	Agricultural Land	1.18	1.14	2.8	0.82	0.8	2.24	20.83	8.43
	Others	0.55	0.42	0.65	0.6	0.64	0.96	2.54	2.03
2017	Dense Forest	44.79	62.08	53.66	60.5	59.85	31.04	5.07	15.61
	Open Forest	16.16	6.68	12	18.67	18.48	10.68	0.86	3.14
	Other Wooded Land	8.85	5.18	4.62	4.06	5.25	5.9	4.03	4.33
	Scrubland	12.48	1.8	2.78	4.54	1.64	6.4	4.04	9.64
	Grassland	8.76	3.52	9.53	5.84	3.49	4.28	9.18	4.69
	Water	0.17	0.11	0.22	0.1	0.14	0.49	0.37	1.44
	Agricultural Land	8.13	20.15	16.76	6.11	11.09	40.76	74.43	59.52
	Others	0.66	0.47	0.43	0.19	0.05	0.45	2.01	1.63

Table 10. Error matrix calculated from supervised maximum likelihood classification in 2017

LULC class	1	2	3	4	5	6	7	8	Total	U_Accuracy	Kappa
1	266	17	7	0	0	0	2	0	292	0.91	0
2	2	80	2	0	0	0	0	0	84	0.95	0
3	0	3	34	2	0	0	1	0	40	0.85	0
4	0	0	8	38	0	0	2	0	48	0.79	0
5	0	0	0	4	42	0	2	0	48	0.88	0
6	0	2	2	0	1	4	1	0	10	0.4	0
7	1	9	12	3	1	0	178	0	204	0.87	0
8	1	1	1	0	0	0	0	7	10	0.7	0
Total	270	112	66	47	44	4	186	7	736	0	0
P_Accuracy	98.52	71.43	51.52	80.85	95.45	100	95.7	100	0	88.18	0
Kappa	0	0	0	0	0	0	0	0	0	0	84.32

Table 11. Error matrix calculated from supervised maximum likelihood classification in 2006

LULC Class	1	2	3	4	5	6	7	8	Total	U_Accuracy	Kappa
1	286	27	5	0	0	0	0	0	318	0.9	0
2	6	104	17	2	0	0	4	0	133	0.78	0
3	0	4	100	5	0	0	10	0	119	0.84	0
4	0	1	5	74	0	0	15	2	97	0.76	0
5	0	0	0	1	10	0	0	0	11	0.91	0
6	0	0	0	0	0	10	0	0	10	1	0
7	1	0	0	1	0	0	36	0	38	0.95	0
8	0	0	0	0	0	0	3	7	10	0.7	0
Total	293	136	127	83	10	10	68	9	736	0	0
P_Accuracy	97.61	76.47	78.74	89.16	100	100	52.94	77.78	0	85.19	0
Kappa	0	0	0	0	0	0	0	0	0	0	80.16

Table 12. Error matrix calculated from supervised maximum likelihood classification in 1990

LULC Class	1	2	3	4	5	6	7	8	Total	U_Accuracy	Kappa
1	345	51	2	0	0	0	1	0	399	0.86	0
2	3	46	10	0	0	0	0	0	59	0.78	0
3	0	5	46	1	0	0	3	0	55	0.84	0
4	0	1	6	124	1	0	25	0	157	0.79	0
5	0	0	0	1	8	0	1	0	10	0.8	0
6	1	0	1	1	0	5	2	0	10	0.5	0
7	0	2	1	6	1	0	35	2	47	0.74	0
8	0	0	0	0	0	1	1	8	10	0.8	0
Total	349	105	66	133	10	6	68	10	747	0	0
P_Accuracy	99	44	70	93	80	83	51	80	0	82.6	0
Kappa	0	0	0	0	0	0	0	0	0	0	74.75