University of Tartu

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Master Thesis in Geoinformatics for Urbanized Society (30 ECTS)

Deforestation in Peninsular Malaysia from 2001 to 2018

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Tartu 2020

Abstract

Title: Deforestation in Peninsular Malaysia from 2001 to 2018

Deforestation is a serious issue faced by many tropical regions including Peninsular Malaysia. Forest in Peninsular Malaysia is among the oldest forest in the world and is inhabited by high number of endemic species. Therefore, this study aimed to estimate the deforestation in Peninsular Malaysia from 2001 until 2018. Forest loss and forest cover data was acquired from Global Forest Change (GFC) dataset developed by Department of Geographical Sciences, University of Maryland. To achieve the objectives of the research, the forest loss data was analyzed in relation to the general trends of loss, which includes temporal patterns, patch sizes, distribution by slope and protected areas. In addition, hot spot analysis of the forest loss was performed, and possible causes of deforestation discussed. The results suggest that agriculture, especially establishment of commercial plantation, was the major factor of deforestation in Peninsular Malaysia from 2001 to 2018.

Keywords: Deforestation, spatial analysis, remote sensing

CERCS code: T181 Remote sensing

Abstrakt

Pealkiri: Metsade kadu Malaka poolsaare lõunaosas aastatel 2001 kuni 2018

Metsade kadu on tõsine probleem, millega seisavad silmitsi paljud troopilised piirkonnad sh Malaka poolsaar. Malaka poolsaare metsad on ühed vanimatest metsadest maailmas, seal eluneb suurel hulgal endeemilisi liike. Seetõttu oli käesoleva uurimistöö eesmärgiks vaadelda metsade kadu Malaka poolsaare lõunaosas aastatel 2001 kuni 2018 kasutades kaugseirel põhinevat andmestikku ja GIS meetodeid. Uurimistöös kasutati metsade muutuste andmed (Global Forest Change - GFC) , mis on välja töötatud Landsat satelliidi andmete põhjal Marylandi ülikoolis. Uurimistöös uuriti metsade muutust ajas ja ruumis Malaka poolsaare lõunaosas ning tuvastati metsa kao tulipunktid erinevatel aastatel. Lisaks analüüsiti muutusi erineva reljeefiga aladel – tasastel ja suure nõlvakaldega aladel. Detailsematel uurimisaladel vaadeldi metsade kao põhjuseid. Selgus, et aastatel 2001 kuni 2018 oli Malaka poolsaare lõunaosa metsade kao peamiseks põhjuseks põllumajandus, eriti tootmisistandused sh õlipalmi istandused.

Võtmesõnad: metsade kadumine, ruumianalüüs, kaugseire

CERCS kood: T181 Kaugseire

Contents

Introduction

The United Nation’s Food and Agriculture Organization (FAO, 2015) defines forest as a land area of less than 0.5 ha with tree canopy covering more than 10% and not primarily categorized under agricultural purpose or other specified non-forest use, and young forests and regions where tree growth is climatically repressed, the trees are able to achieve 5m growth (Hamid & Abd Rahman, 2016). Forest plays several important ecological roles from helping to mitigate climate change, providing food, catchment for clean water supply and medicine which makes all these essential ecological powerhouses irreplaceable (Bosetti & Lubowski, 2013). Other than that, the forest also provides a healthy landscape for the earth, which contributes many benefits to human life.

Tropical rainforest is described as the most important type of forest in the world due to its richness in the ecosystem, the species of flora and fauna and many other resources. By occupying less than seven percent of the land surface, tropical rainforest inhabits half of the species on earth and is economically, ecologically and culturally crucial for issues in global food security, climate change, biodiversity and human health (Monson, 2014). This is logically accepted since the tropical rainforest is located just around the equator where it receives hot climate all year, making it livable for many species, either plants, animals or even human beings.

Since the industrial boom happened in the early 1900s, forests have experienced a very big loss by a phenomenon called deforestation. Deforestation is defined as diminishing of trees without intention of replanting or regeneration, such as conversion of previously forested area to urban, agricultural or other land use, which does not have a substantial tree canopy cover <10% (Latif et al, 2015). The underlying causes of deforestation are not fully understood as it could be related to population growth, poverty, economic development, insecure land tenure and weak law enforcement (Miyamoto et al, 2014). Deforestation and forest degradation represent a significant fraction of the annual worldwide human-induced emission of Greenhouse Gases (GHG) to the atmosphere (Moutinho, 2012). Consequently, deforestation will lead to the disability in control of the GHG emission, which also has its effect on human health. Based on the Forestry Statistic 2018, the global forest area decreased by around 7.3 million hectares (0.2%) per year from 1990 until 2000 and from the year 2000 until 2010, the global forest cover lost around 4.0 million hectares (0.1%) and it continues to lose 3.3 million hectares (0.1%) more until 2015 (Ward and Watson, 2018).

This study focuses on Peninsular Malaysia because during the last decades it has experienced significant deforestation (Latif et al, 2015). Peninsular Malaysia is considered a megadiverse region together with other 16 countries in the world. Megadiverse countries refer to a group of states that harbour most of Earth’s species with high numbers of endemic species and exhibits great biodiversity (Paknia et al, 2015). Most of these countries are located or partially located in tropical or subtropical regions. It means that any deforestation activities in this region cost more than any other forest can offer. In today's world it is fair to say that all deforestation activities occur due to economic factors and lack of awareness towards sustainable development.

Therefore, the objective of this study is to explore the general trends of forest loss, determining the causes of loss and identifying the hotspot regions of forest loss in Peninsular Malaysia. The topic is studied using forest loss dataset from Hansen et al. by applying remote sensing approach and GIS techniques to investigate the forest loss in the period from 2001 to 2018. Hence, the research pursues to answer the following questions;

- What are the temporal and spatial trends of forest loss in Peninsular Malaysia from 2001 until 2018?
- What are the causes of forest loss in the study area?
- Where are the hotspots of the forest loss in Peninsular Malaysia?

This thesis consists of four chapters. The first chapter presents a theoretical overview of the forest monitoring using the remote sensing approach, forest background and situation in the study area. The second chapter explains the data and methods used in this study. The outcome of this research is presented in the third chapter, which includes all the results and analysis. The fourth chapter focuses on discussion and conclusions, explaining how this study is relatable to the research objectives, theoretical parts, methodology and results. The final chapter also includes information on the limitations to the study, as well as recommendations for future research. At the end of the study, a summary is provided to summarize the outcome of the study and how it is applicable to the actual situation.

1. Theoretical Overview

1.1 Application of remote sensing in forest resource monitoring

Environmental tension in forest ecosystem arises because of land-intensification, disturbance limitations or non-sustainable management causing changes in forest health at numerous scales from the local to the globe scale (Lausch et al, 2017). This pressure to the forest ecosystem is hard to control otherwise than by applying law enforcement that would limit human activities from continuously discovering forest areas as a new place. However, implementing a new law does not necessarily lead to the positive results, as there are still some deforestation activities practiced illegally. Not every part of a forest can be physically monitored but there exists technology that can be implied to observe every space of the forest area. Many decisions made by authorities including policymakers and natural resource managers regarding forests are poorly connected with the spatial scales covered by conventional forest inventory methods (Calders et al, 2020). There are various approaches for monitoring forest health using in-situ forest inventory and experimental studies but generally it is very limited in sample size and in order to generate larger scale forest area, as it is time consuming and labor-intensive (Lausch et al, 2017).

In order to overcome this problem, remote sensing is determined as one of the key data sources to fill the existing forest monitoring inventory gaps, especially in many developing countries that are claimed to cause a larger quantity of carbon emissions (Calders et al, 2020). The United Nation Framework Convention on Climate Change (UNFCCC) addressed this issue by adopting a mechanism for reducing emissions from deforestation and forest degradation while giving focus towards sustainable forest management by encouraging the developing countries with financial incentives for emission reductions (Mitchell, 2017). The recommendation by UNFCCC to the developing countries is to implement newly established National Forest Monitoring System (NFMS) by using the combination of Earth Observation (EO) data and field-based inventory to estimate the forest area, carbon stocks and changes (Mitchell et al, 2017). This approach gives opportunity for developing countries to produce biennial report with more transparency, competence, accuracy and consistency.

White et al (2016), list four advanced remote sensing technologies which have the greatest potential to influence forest inventories for strategic, tactical and operational planning, namely Airborne Laser Scanning (ALS), Terrestrial Laser Scanning (TLS), Digital Aerial Photogrammetry (DAP) and High Spatial Resolution (HSR) satellite optical imagery. The ALS is a technique based on the measure of the flight time of laser pulses emitted from an aircraft and reflected by objects located on the ground (Monnet and Emgr, 2012). A study from Dash et al. (2017) found the ability of ALS combining with aerial imagery for invasive conifer detection in New Zealand even the ALS detail imagery can be questionable compare to TLS. TLS technique is a ground base remote sensing system, which can measure vegetation structure in 3D and can be more detailed in terms of the size and the location of canopy elements (Calders et al, 2020). DAP system is comprised of computer hardware and software designed to create photogrammetric products from digital stereo-imagery using a combination of automatic and manual techniques (Goodbody et al, 2019). The HSR has long tradition of utilize airborne imagery to monitor forest inventories starting in 1999 when the first commercial HSR satellite was launched in 1999. An example of forest monitoring using this HSR technique is Wulder et al (2020) that investigates the changes in tree colour in a Canadian forest.

Numerous other studies have proved the success of remote sensing technique for monitoring very detailed forest issues. Banskota et al (2014) review forest monitoring using Landsat time-series data, stating that forest can be distinguished either by the current state and temporal dynamics and these dynamics can outcome from any combination of short-term events, longer-term variability attributable to climate change and human activities. Chiang et al (2016), investigated satellite images to identify forest tree species distribution in Mongolia and successfully determined four different types of trees which demonstrated relatively well the ability of remote sensing technology to classify forest tree species. From all the listed remote sensing technologies for forest inventory, it proves the ability of big data to monitor forest activities from many different angles: from far at the top or even closer with more detail 3D abilities. With the technology of big data becoming more sophisticated, the outcome of the data becomes more accurate.

1.2 Global Forest Change dataset

Changes in forest cover plays an important role for biodiversity, climate, carbon storage and water cycle in the world. However, acquiring detailed information about global forest change spatially and temporarily at global scale is a complex task. Hansen et al (2013) mapped global tree cover extent, loss and gain for the period from 2000 to 2012 at a spatial resolution of 30m with the tree cover loss mapped annually at global scale. The map is globally known as Global Forest Change (GFC). In the process of its creation, global Landsat analysis was performed using Google Earth Engine and a total of 654 178 growing season Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images were analyzed (Hansen et al, 2013). Based on the ETM+ time-series images, the authors calculated several metrics using the reflectance values and applied a decision tree algorithm to map the forest dynamics. The establishment of GFC analysis improves on existing knowledge of global forest extent and change in four major benefits (i) being spatially explicit; (ii) the gross forest loss and gain were performed quantitatively; (iii) it provides the information of annual loss and quantifying trends in forest loss; and (iv) being derived through an internally consistent approach that is exempt from vagaries of different definitions, methods and data inputs (Hansen et al, 2013).

Regarding the quality of the GFC dataset, Feng et al (2016) claimed that the GFC has an overall accuracy of >88% which is among the highest accuracies reported for recent global forest and land-cover data products. This is due to the fact that GFC dataset is able to perform correct patterns despite having regional bias and the continuous percentage of tree cover layers can be easily divided into classes within a country or region with differing ecological characteristic and disturbance histories (Mitchard, 2016). In addition, other studies also stated that the GFC map has highest validity of spatial studies for forest monitoring, such as studies from Bos et al (2019), Vieilledent et al (2018) and Marle et al (2016). Even with some issues related to the accuracy, the GFC still remains a valuable source of forest cover information for regions where local data is severely absent (Burivalova et al, 2015). Furthermore, GFC dataset is the only available global deforestation dataset that has a high spatial resolution (Viergever et al, 2015).

Like many other remote sensing products, the GFC dataset has many issues and has been criticized for inaccuracies especially in determining vegetation types at the local scale (Martin and Lian, 2015). Moreover, measuring accurate tropical forest cover in the humid tropics using cloud free days images from the dry season will be affected because the vegetation is not as green as during the rainy season (Cunningham et al, 2019). Other than that, Cunningham et al (2019) stated that the GFC map strongly underestimated tree cover below 189 mm of precipitation and at elevation above 2000 m with a larger bias for precipitation. In addition, Harris (2018) compared GFC dataset with REDD++ (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) countries datasets and found out that countries with much smaller scale deforestation tend to have lower number of deforested area in GFC dataset. At the same time, countries with much larger scale deforestation recorded higher number for GFC than in local dataset. Viergever et al (2015) added that the errors regarding the usage of GFC were only reported in terms of user's and producer's accuracy and not considering the errors caused by omission and commission.

The GFC dataset offers a critical approach for measuring the efficiency of global forest conservation efforts and when this data effectively combined with other datasets, it can produce many new usable outcomes that has a variety of international standards (Elias, 2013). The remote sensing used to develop the GFC dataset allow for the results to be used flexibly because it has the ability to be scaled down to the local level or to be used globally. It means, regardless of the scale, the GFC dataset can still provide useful information on forest cover loss in the targeted area.

1.3 Forest management in Malaysia

Malaysia's forest is acknowledged to be among the most complex ecosystems in the world. The natural forest of Malaysia is divided into seven major types of forest, namely the Lowland Dipterocarp Forest (300m above mean sea level), Hill Dipterocarp Forest (altitudinal limits of 300m and 750m), Upper Dipterocarp Forest (altitudinal limits of 750m to 1 200m), Lower Montane Forest (altitudinal range of 1 000-1 500m), Upper Montane Forest (altitudes of more than 1 500m), Peat Swamp Forest and Mangrove Forest (Kamaruzaman and Dahlan, 2008).

1.3.1 Forest management, laws and regulation in Malaysia

Malaysia was formed in 1963 and comprises three regions: Peninsular Malaysia, Sarawak and Sabah. Peninsular Malaysia is composed of 11 Federated Malay States, which attained independence in 1957 from the British government. The forest administration is divided into three separate bodies, the Peninsular Malaysia Forestry Department, The Forest Department Sabah and Forest Department of Sarawak. The administrative power, jurisdiction and related responsibilities are usually shared between the federal and state governments. The 13 state governments have jurisdiction over agriculture, land and soil conversion, rivers, water resources, fisheries and forest resources as issued under Article 74(2) of the Malaysian Constitution (Policies, 2016). Each state is authorized to enact laws on forestry and to formulate forestry policy independently while the federal government only provides technical advice and assistance on forest management, the conduct of research, training and the maintenance of experimental and demonstration stations (Woon & Norini, 2013). The main federal body that is responsible for forest policy is the Department of the Environment within the Ministry of Natural Resources and Environment (Bakar et al, 2004).

While each state has the authority for the individual forestry rules, there are two key forest policies in Malaysia, namely, The National Forest Act of 1984, and The National Forest Policy of 1978 and plus all following amendments (Kamaruzzaman & Dahlan, 2008). These policies are formulated to ensure that forest management areas should be protected illegal harvesting, unauthorized settlement and other unpermitted activities (Woon & Norini, 2013.). As one of the elements in legal compliance for the forestry sector is that all logging operations that are greater than an area of 500 hectares must carry out an Environmental Impact Assessment (EIA) before going to be executed. The same rule applies to pulp and paper mills with the production of more than 50 tons per day (Woon & Norini, 2013). Generally, forest in Malaysia is categorized into two types: reserve forest and commercial forest. In case of commercial forest, every state in Malaysia is allowed to open new logging area in order to get the state resources but all the policies and regulation run under the Federal government must still be obeyed.

The National Forest Act of 1984 and The National Forest Policy of 1978 are the key policies of forest management in Malaysia, supported by many other policies that have indirect contribution to the main policies. This includes the Federal Constitution, National Land Code (Act 56 Year 1965), 1994 Minerals Development Act (Act 525), Environmental Quality Act 1974 (Act 127), Wildlife Conservacy Act 2010 (Act 716), Criminal Procedure Code 1999 (Act 593) and International Endangered Species Trade Act 2008.

1.3.2 Deforestation causes in Peninsular Malaysia

Yong (2015) categorizes major direct reasons for deforestation and forest degradation drivers in Malaysia, suggesting five categories that include industrial logging, indirect consequences of logging, conversion of forested lands, infrastructure and urban development projects and consumer demands for logs and agriculture. The industrial logging in Peninsular Malaysia can be classified as legal and illegal. In recent years, Peninsular Malaysia Forestry Department, Sarawak Forestry Department and Sabah Forestry Department reported that the inspection of logging area and the total quantity of timber produced is becoming more stringent. This illegal logging issue can be notified easily by the forestry departments since the logging activities were occurred outside of the legal logging borders. One of the examples that shows that the logging activities have clearly reached the limit is when it results in environmental impact, such as landslide or murky river. Yusoff et al (2015), found very high magnesium and iron content in a chalky river water in Kelantan state and it is believed that the situation happened due to some logging activities, which did not follow the Standard Operational Procedures (SOP) where it is not allowed for any logging activities within 10 to 50 meters buffer zones of water bodies.

Palm oil plantations are among the reasons for tropical forest loss, as their expansion causes changes in land use, which lead to a decrease in forest area (Lewis, 2017; Baiya et al, 2018). During the last four decades, the growing and processing of oil palm has been the leading cause of tropical deforestation, greenhouse gas emissions and biodiversity loss especially in Malaysia and Indonesia, which together reported around 85 percent of world palm oil production in 2017 (Chong et al, 2017; Wicke et al, 2011). In addition, the climate change will give big effect to the tropical forest since the region is becoming hotter and more humid, increasing also the risk of fires. Even though Malaysia ranked second for palm oil production, it ranks only fifth in world major consumers of palm oil behind India, Indonesia, European Union and China (Ferdous et al, 2015). West Malaysia produced more palm oil than East Malaysia but with some new plantation areas in East Malaysia, this number might change in the future (Ferdous et al, 2015).

The clearance of natural forest or conversion of forested lands to other land uses is among the main deforestation issues in newly industrialized countries that experience rapid growth in their economy. In Malaysia, these activities include oil palm and other industrial tree plantation, agricultural expansion, dams for hydroelectricity, mining and quarrying. According to Johan and Zahari (2017), Malaysia has supplied almost 39% and 44% of global palm oil production and global export for palm oil, with only Indonesia having a larger production. Mining and quarrying industry is still relatively popular in Malaysia. The tin industry, which once was really booming, is nowadays almost non-existent. However, other minerals are still comparatively high in demand: natural gases, aggregates for building, bauxite, limestone and kaolin.

The number of dams built in Malaysia for producing hydroelectricity is increasing; this applies also to the peninsular area. Compared to others, the dams in Peninsular Malaysia are used relatively more frequently as water reservoirs but there are also several dams that are used for generating electricity. Dams are allegedly among the biggest causes for deforestation in most of the major forests in the world. Barbosa (2008) states that dams flood thousands of hectares on forest and endanger many features of the Amazon basin. All dams in Peninsular Malaysia took a massive forest area especially Kenyir dam and Temenggor dam. After 2000, Sarawak state initiated multiple dam projects and some of them have already been completed, such as Bakun Dam (2011), Murum Dam (2014) and Baram Dam (2016). Bakun Dam is considered among the biggest and tallest hydroelectricity dams in the world and it has caused approximately 700sq km of forest area being underwater, equivalent to the size of Singapore (Lee et al, 2014). The environmental impact of Bakun Dam is not limited to the forest loss, but also to some of the highest rates of plant and animal endemism, which it is believed that those species only can be found in the region and nowhere else on Earth. In February 2010, it was announced that the level of water of Bakun Dam has reached 228m.

Infrastructure and urban development projects in Peninsular Malaysia can also be observed as among the active contributors to deforestation. This includes the construction of roads and highways, airports, industrial parks, housings and tourism facilities such as resorts and theme parks. As a region that is more focus on business and economy, Peninsular Malaysia does well in terms of providing infrastructures to citizens. Malaysia as a whole ranked 8th in Asia and 25th in the world as having the most developed overall infrastructure (Ng et al, 2019). Malaysia Expressway System has a total length of 1 821km and is considered as third best in Asia after Japan and South Korea (Ng et al, 2019). Electric Train Service (ETS) that was built connecting the northern area of Peninsular Malaysia to the southern area, was opened in 2010 and has made the traffic between cities more active. The Kuala Lumpur International Airport 1 (KLIA) and 2 (KLIA2) are ranked as one of the busiest airports in the world. However, with all these world-class infrastructures, Malaysia struggles to remain a very sustainable country. Even though the Rawang Bypass Highway project that was completed in 2018 was claimed to be sustainable, it still reduced the total area of forest involved from 65 hectares to 24 hectares. The highway also crosses the Kanching Forest Reserve, which may be disrupting the ecosystem there (Affendi et al, 2013).

1.3.3 Land development plan program in Peninsular Malaysia

Since independence from the British in August 1957, Peninsular Malaysia has developed many economic development plans with the main focus to modernize the country, reduce the gap between urban and rural areas and increase the quality of life of the population. This includes the introduction of several land development programs with the aim to maximize agricultural resources. As a tropical country where the crops are able to grow during the entire year, the programs consider increasing the income of the population in rural areas by encouraging them to involve in the agricultural sector as a good idea. All these programs involved opening of many new government-owned lands as well as assisting the private-owned land in order to increase the productivity by providing funds, skills and agricultural equipment.

FELDA (Federal Land Development Authority) covers the biggest land area among all other land development programs, followed by FELCRA (Federal Land Consolidation and Rehabilitation Authority). FELDA was formed on 1st of July 1956 under the Land Development Act that was implemented at that time. Until 2009, FELDA holds approximately 811 140 hectares (2 004 400 acres) land area in Malaysia, mainly in the Peninsular Malaysia (Hussin, 2013). Palm oil plantations cover the biggest plantation area, followed by rubber. The establishment of FELDA has involved opening many new lands which needed forestry areas are being deforested. Every FELDA settlement use very huge area because the land-use is not only focus as agricultural purposes, but also housings and infrastructures for farmers and families (Bakar *et al.*, 2004). Even though there are no new settlements established since 1990s, FELDA is still engaged in a diversified range of business activities and economic development. In 2019, FELDA planned to utilize almost 40 000 hectares of its less productive lands to become more commercialized agricultural-based land that uses highly intensive technology (Hussin, 2013).

FELCRA (Federal Land Consolidation and Rehabilitation Authority) is a governmental organization that was established on 1st of September 1997 with the main objective to improve the economy of rural areas by encouraging the rural inhabitants to become more active in entrepreneurship and agriculture sectors. Unlike FELDA, that provides for almost every need and infrastructure to the participants, the contribution of FELCRA is only limited to economic needs. FELCRA will identify wastelands in rural areas and help the owners to utilize the lands by providing funds, equipment and skills. This includes opening many new agricultural areas on the area that was before covered by forest. Until 2018, FELCRA has already developed almost 257 078 hectares of agricultural areas that involve palm oil plantation, rubber and rice. In addition, FELCRA has also efficiently managed around 2 000 agricultural projects since its establishment.

In addition to FELDA and FELCRA, there are many other land development programs being introduced with almost similar objectives. Most of these programs are run at local authority's level, such as KESEDAR (South Kelantan Development Institution), Sime Darby Berhad, PR1MA (1 Malaysia Housing Development Project), RISDA (Rubber Industry Smallholders Development Authority) and Iskandar Malaysia. All these land development programs have boosted many new land openings, leading to a large number of deforestation activities and this issue is receiving a lot of attention in Peninsular Malaysia.

2. Data and Methodology

2.1 Study area

Peninsular Malaysia, also known as West Malaysia, is located in the Southeast Asian region, as part of Malaysia's divided land where the other part belongs to East Malaysia (Borneo). It shares land border with Thailand in the north and ocean border with Singapore and Indonesia in the south and west. Peninsular Malaysia and East Malaysia are separated by South China Sea. Peninsular Malaysia is relatively smaller than the East Malaysia with 132 265 km^2 (40% of the Malaysia's area), despite it has 12 out of 14 states in Malaysia and inhabited by 78% of total population of Malaysia.

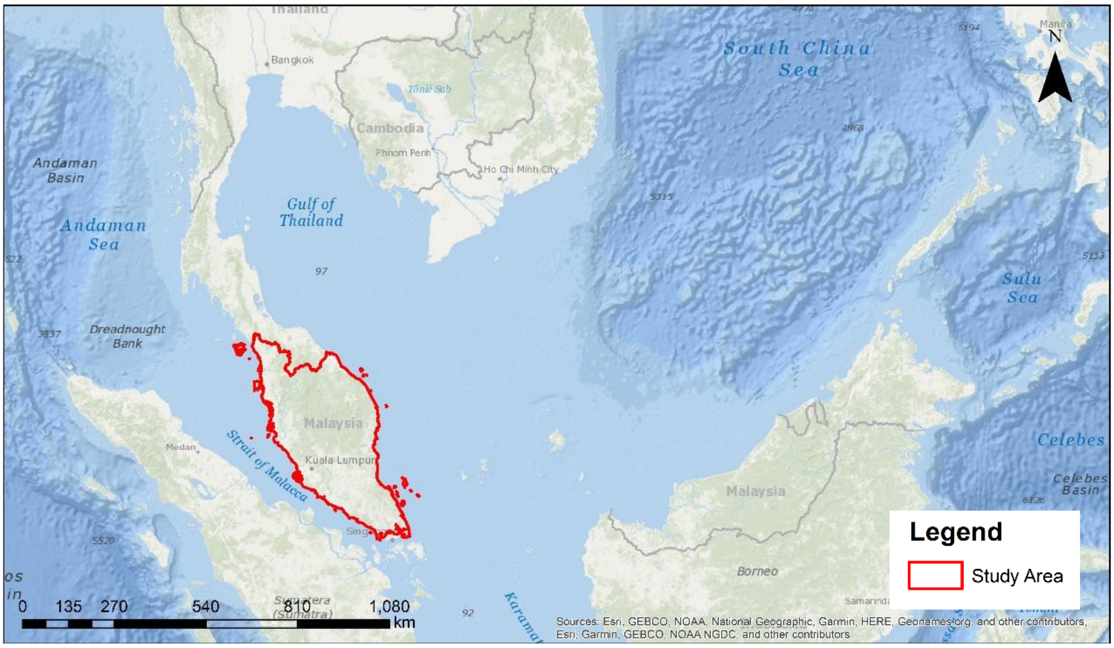

Figure 1: Study area map for Peninsular Malaysia (Basemap: Esri ArcGIS Oceans)

Located near the equator, Peninsular Malaysia has humid tropical climate. Due to the geographical factor, the weather is categorized as equatorial - it is hot and humid throughout the year. Peninsular Malaysia has the yearly average temperature of about 27°C and 2343.1 mm of average precipitation every year (Wong et al, 2018). A study from Wong et al (2018) also shows that the climates of the Peninsular and East Malaysia slightly differ, as the Peninsular is highly affected by wind from mainland, while the East has more maritime weather.

Peninsular Malaysia has several mountain ranges. The Titiwangsa Mountains is the main mountain range that divides the east and west coast. Malaysia in general is listed as one of the 17 megadiverse countries in the world with around 15 000 plant species (Paknia et al, 2015). Because of the temperature is significantly warm and rainy, Peninsular Malaysia has huge advantages for crops production and forest resources.

2.2 Data

2.2.1 Global Forest Change dataset

The global high-resolution (30-m) Global Forest Change (GFC) raster dataset was developed and processed by the Department of Geographical Sciences, University of Maryland using Landsat imagery. The Landsat imagery analysis was accomplished using Google Earth Engine (Hansen *et al.*, 2013). The dataset was downloaded from (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html).

In order to produce precise forest cover and loss maps, two layers of raster datasets are needed: for tree cover and forest loss. In tree cover dataset, trees and all vegetation taller than 5m in height was covered and forest loss was defined as a stand-replacement disturbance (Hansen et al, 2013). The forest loss meaning in the dataset does not necessarily mean forest cut but it includes any forest disturbance issues such as forest fires (Hansen et al, 2013; Kalamandeen et al, 2018). The tree cover dataset shows the tree cover of Malaysia in 2000, whereas the forest loss data is presented yearly from 2001 until 2018. The forest loss data also includes a layer that shows untouched forest, inhabitant areas and water bodies as one unit. To obtain the datasets that only cover the Peninsular Malaysia, two granules (10N, 100E & 10N, 90E) are required. These datasets are clipped with the Peninsular Malaysia administrative shapefile for preferable visualizations.

2.2.2 DEM

This study also includes the usage of Digital Elevation Model (DEM) acquired from Shuttle Radar Topography Mission (SRTM) datasets (http://dwtkns.com/srtm/). SRTM data are organized into rasterized cells or it is also called tiles where each tile covering 1° by 1° in latitude and longitude (Yue et al, 2017). There are three tiles from SRTM was used (strm_56_11, srtm_57_11 and strm_57_12) to complete with the area of Peninsular Malaysia.

2.2.3 Administrative borders and protection zones

There are two vector datasets used in this study, which are the Malaysia administrative boundaries, protected areas in Malaysia. The administrative boundaries of Malaysia were obtained from Global Administrative Area Database (GADM: http://gadm.org/). The dataset for protected areas in Malaysia was obtained from the International Union for Conservation of Nature (IUCN) dataset (https://www.protectedplanet.net/country/MY).

2.2.4 Palm oil plantation areas

The palm oil plantation areas dataset was obtained from Xu et al (2020) through (https://www.earth-syst-sci-data.net/12/847/2020/). The dataset consists of the palm oil plantation areas in Malaysia and Indonesia from 2001 until 2016. The data was created by combining the optical and microwave satellite observations at 100m resolution using the image classification and change detection (Xu et al, 2020).

2.3 Methods

To detect the general deforestation trends from 2001 to 2018, forest loss was calculated from GFC dataset. The initial tree cover map for the 2000 was obtained from GFC dataset by using a tree cover threshold of 30% (Morton et al, 2011) (Milodowski et al, 2017). Forest cover in 2018 is recognized by deleting forest loss from forest area 2000 with all the forest area from 2001 until 2018. Since the forest loss dataset is presented by year, the annual deforestation trends study is done by converting the pixel counts into km^2 (100 hectares = $1km^2$).

To analyze the size of deforested patches by year, deforestation patches were categorized into eight categories, namely ≤1 ha, ≤6.25ha, 6.25–50ha, 50–100ha, 100–200ha, 200–500ha, 500–1 000ha and >1 000ha. These patch categories were also used by Kalamandeen et al (2018) and Montibeller et al (2020).

To analyze the forest loss by slope, the slope was derived from the SRTM DEM dataset and slope was reclassified into seven categories: <5°, <10°, <15°, <20°, <25°, <30° and >30°. While the classification of percentage of deforested slope by year was calculated by using the equation below:

$$\%\ \text{of deforested slope}_{\text{v2001}} = \frac{Forest\ loss\ slope_{\text{v2001}}}{Total\ forest\ loss_{\text{v2001}}} \times 100$$

v = degree of slope

To identify the proportion of forest loss in the protection zones, the deforestation dataset was clipped with the protected areas.

More detailed study areas were chosen to identify the causes of forest loss. Google Earth high-resolution imagery was used to identify and validate manually the causes of deforestation. This method also was used by Curtis et al (2018) and Khadka & Mahatara (2019) who divided deforestation causes into five categories, (i) commodity-driven deforestation; (ii) shifting agriculture; (iii) Forestry; (iv) Wildfire; (v) Urbanization (Figure 2). The commodity driven deforestation is defined by the long-term previously forested area changes to non-forest land use for agricultural purpose such as palm oil plantation, mining or energy infrastructure. Shifting agriculture is defined as small to medium scale of forest and shrubland, which previously was used as agricultural land then later is abandoned then followed by subsequent forest growth. Forestry is defined as large-scale forestry operations occurring within managed forests and tree plantations with prove of the forest regrowth in subsequent years. Wildfire is defined as burning of the large-scale of forest vegetation without conversion to agricultural activities by human afterward. Lastly, the urbanization forest loss is defined as forest and shrubland conversion for the expansion and intensification of existing urban centers. The same classification was used in the current study. The Google Earth time-series imagery was used to visually inspect all available high-resolution images before, during and after the year of loss to identify the cause of the disturbance in each region of the cell containing tree cover loss.

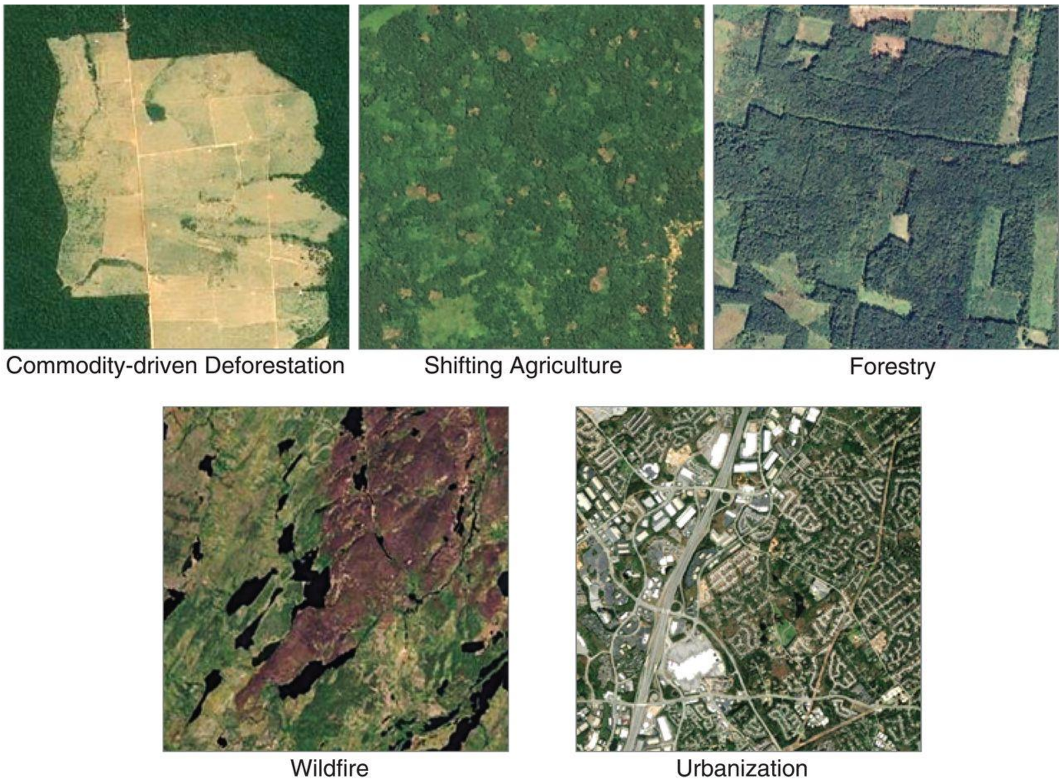

Figure 2: Representative examples of Google Earth imagery used to train the forest loss classification (Curtis et al., 2018).

Lastly, hot spots analysis was performed. Harris et al (2017) define hot spots as an area that exhibits statistically significant clustering in the spatial pattern of forest loss. In order to identify deforestation hotspots, the ESRI Hot Spot Analysis Getis-ord Gi* is used. These analyses were conducted using the spatial statistic in ArcGIS 10.6 using fixed distance of 10 km (Montibeller et al, 2020). Both hot spots and cold spots were identified with only spots with a confidence interval ≥90%. The Getis-Ord Gi* statistics generates Z scores (standard deviations) and P values that indicate whether features are statistically clustered at a given distance (Sanchez-Cuervo and Aide, 2013). A Z score above 1.96 or below -1.96 means that the variable evaluated (Pearson's correlation coefficient R) shows either a statistically significant hot spot (high R values) or a statistically significant cold spot (low R values) at a significance of $P < 0.05$ (Sanchez-Cuervo and Aide, 2013).

3. Results

3.1 General forest loss trends in Peninsular Malaysia

3.1.1 Temporal and spatial trends of forest loss

The total of forest loss in Peninsular Malaysia from 2001 until 2018 was 40722.16 km². During those 18 years, 2014 recorded the highest loss with 3 473.9 km² and the lowest of loss was recorded in 2003 with 913.03 km². The Peninsular Malaysia lost 2264.34 km² of the forest area every year with the annual rate of 2.03%. In total, from 2001 until 2018, Peninsular Malaysia lost almost 31% of the forest area.

The temporal trend in Peninsular Malaysia is significantly fluctuating (Figure 3). 2001, the forest loss area was 2 202.69 km² and had slight increase in the next year to 2 128.19 km². The number suddenly dropped drastically in 2003 with 913.03 km² and increase drastically as well in 2004 to 1 851.63 km². This trend continues until 2018 with the forest loss area recorded for that year was 2469.05 km². As overall, the total of forest area in Peninsular Malaysia has been constantly decreasing from 2001 to 2018 by almost 30 000 km².

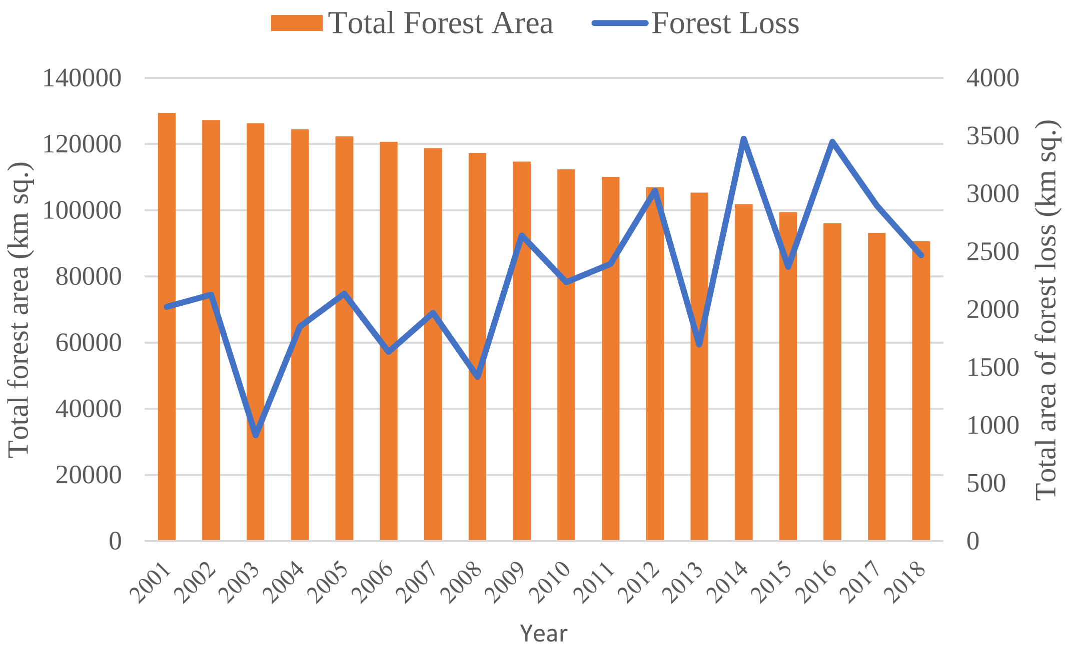

Figure 3: Trends and flows of forest area and forest loss by year (2001 - 2018).

By observing the location of the forest loss in Figure 4, the distribution of the forest loss was spread all over the region except in the high elevation area in the central part in the Titiwangsa Mountains and Tahan Range, and certain coastal areas. According to the zoomed images, the spatial pattern of forest loss is continuous where the locations of loss in recent years are neighbored with the loss of the earlier years. It shows most of the loss is caused by the human activities.

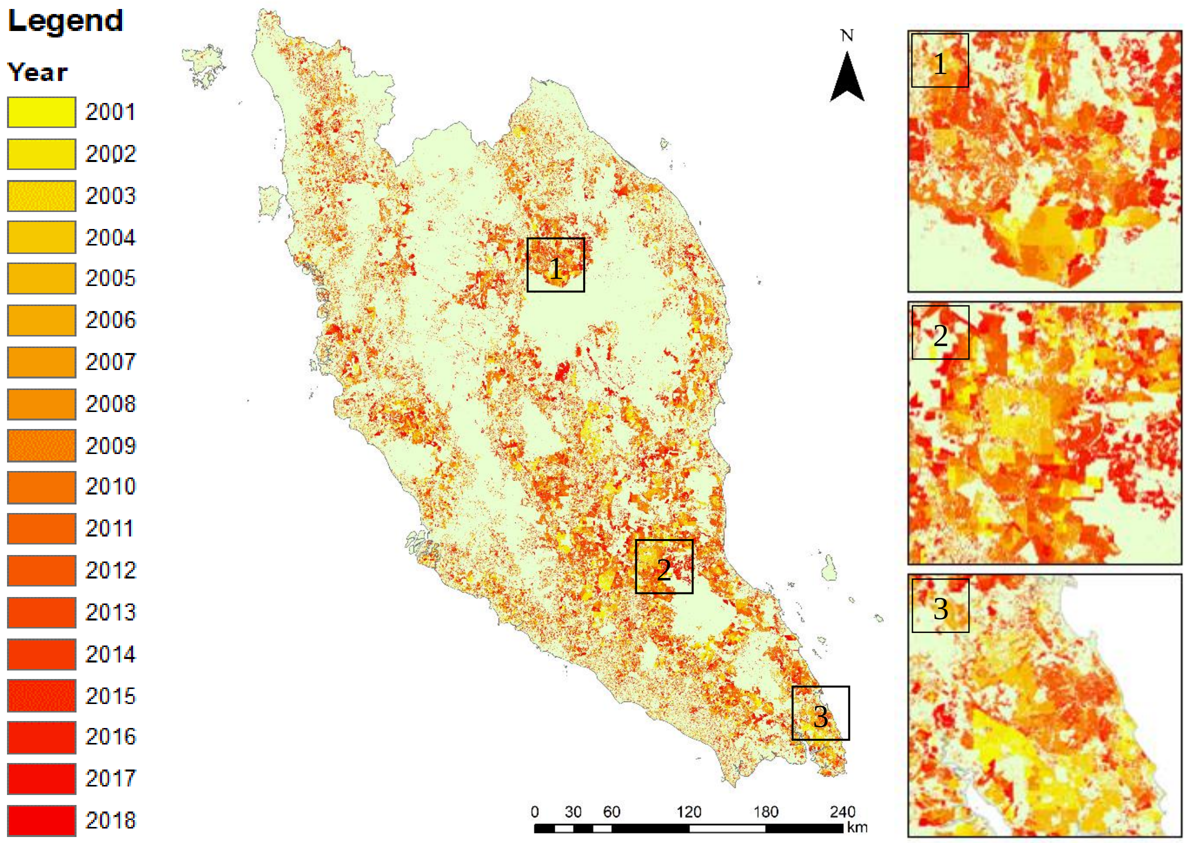

Figure 4: Forest loss areas by year (2001 - 2018) with three zoomed location. 1) Zoomed location for east coast region. 2) Zoomed location for central region. 3) Zoomed location for southern region.

3.1.2 Forest loss distribution according to patch sizes

According to Figure 5, almost every patch size category shows a slight increase in total except for the patch size ≥1 000 ha Total forest loss in 2001 and 2002 is lower than in the year of 2015 until 2018. However, 2001 and 2002 has higher number of large patch sizes compared to the last four years. Mean number of patch ≥1 000 ha for 2001 and 2002 are 22 and for 2015 until 2018 is only four patches. Overall, the total of forest loss does not give much influence for the larger patch sizes which contribute to the findings where the trends of large-scale deforestation is decreasing.

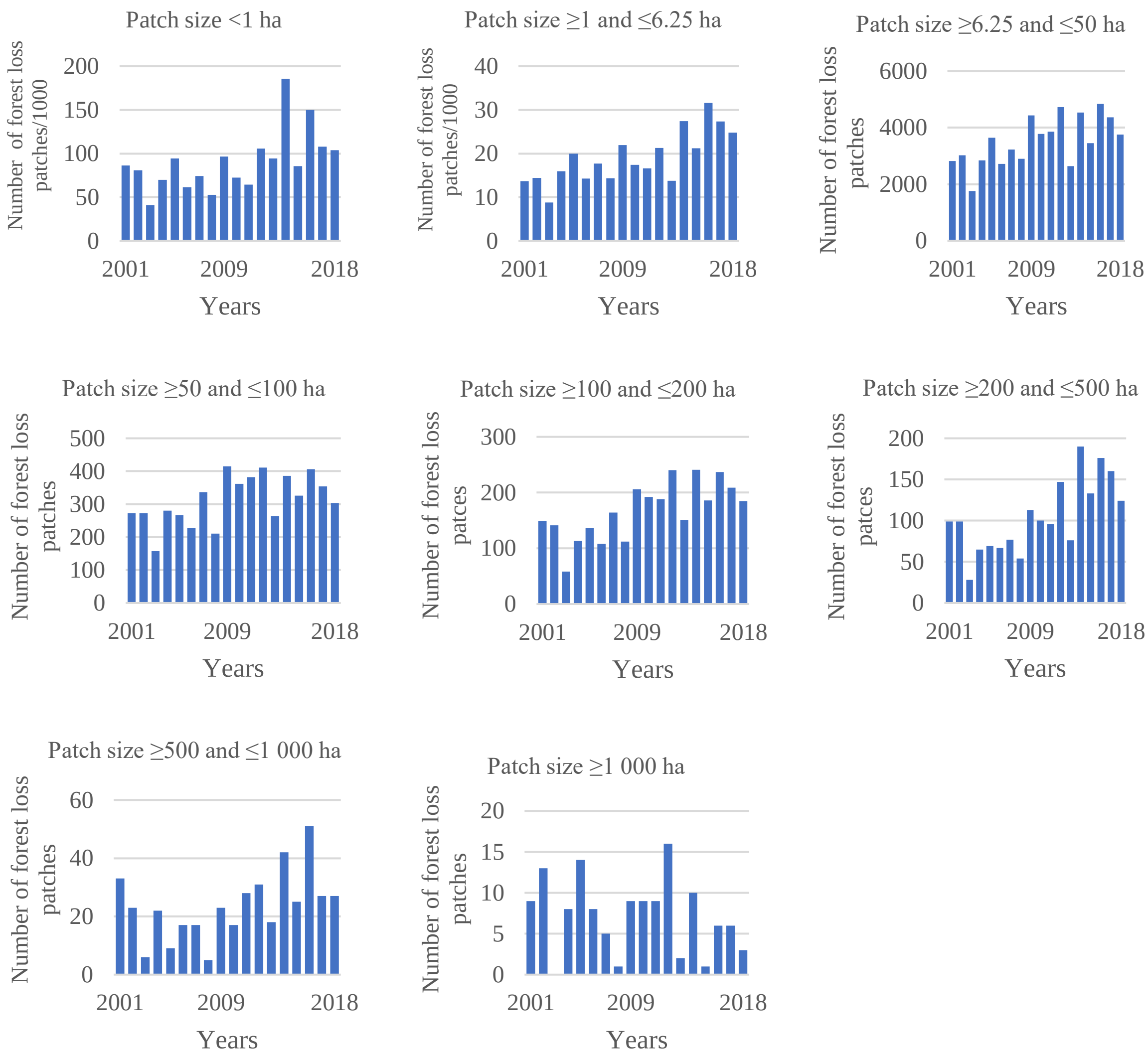

Figure 5: Annual forest loss patch size distribution from 2001 to 2018.

3.1.3 Forest loss trends by slope

Analysis of forest loss by slope showed that more than 90% of the forest loss occurred at the slopes that are lower than 5° and 6.8% occurred on slopes of 5° to 10°. High slope areas have less forest loss because they are harder to reach and work on. The southern region has higher forest loss due to rather flat landscape compared to the northern region (Figure 6). The forest loss on the higher slopes can be seen mostly in the west coast and east coast region where the high mountains and ranges are located.

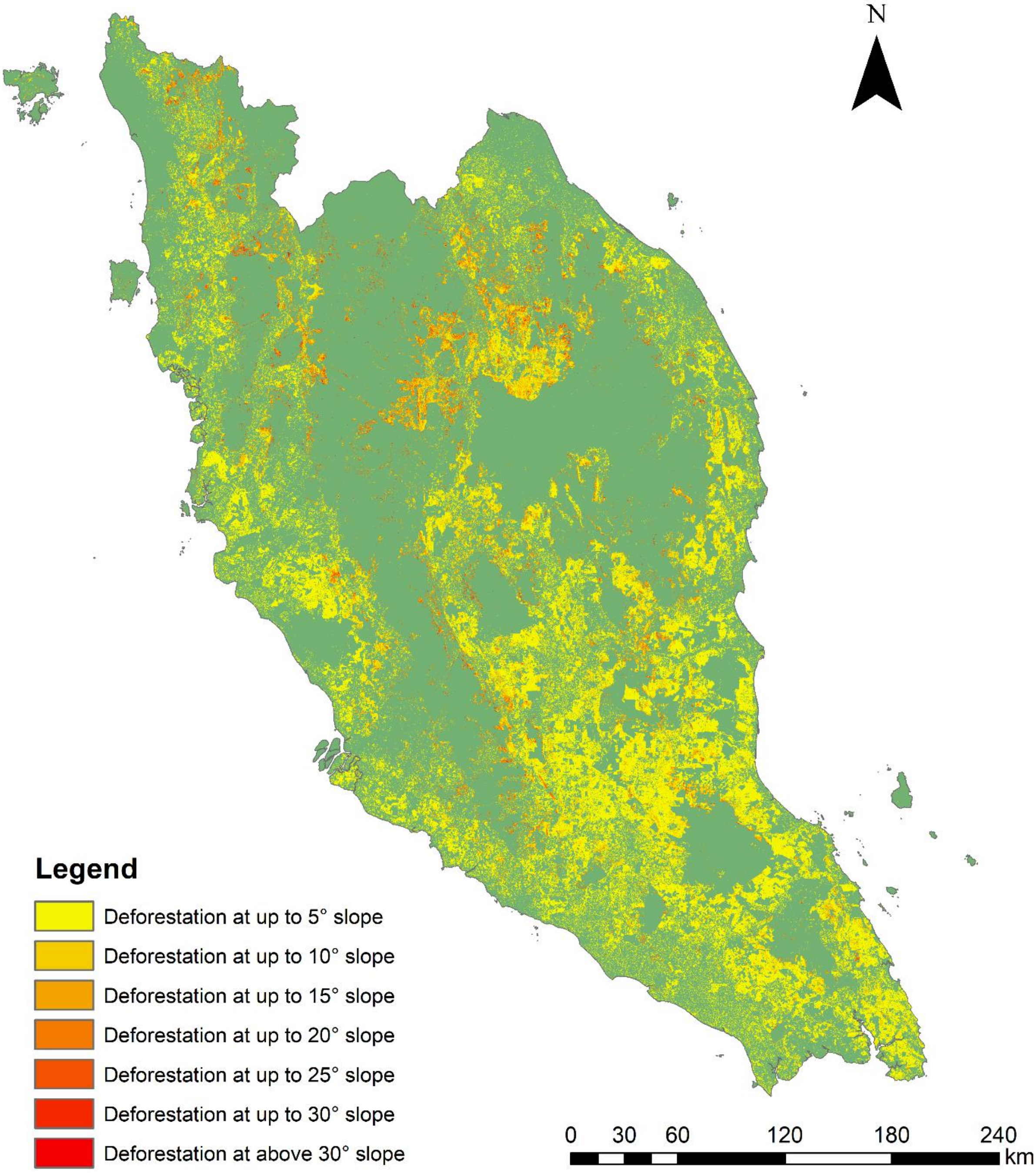

Figure 6: Forest loss distribution in seven different slope categories.

Figure 7 shows the percentage of annual deforestation by slope for <20° slope area and >20° slope area. From the chart, it is clear that the forest loss increases in time on more steep slopes while in lower slope is continuing to increase also but gradually compare to the steep slopes. Deforestation on steep slopes (over 20°) increased from 0.03% to 0.22% from 2001 to 2018. The lower slope has slight increase due to the fact that there is not much forest area left at the lower slope area and the forest loss at higher slope increase drastically since most of the forest in the area is still not touch.

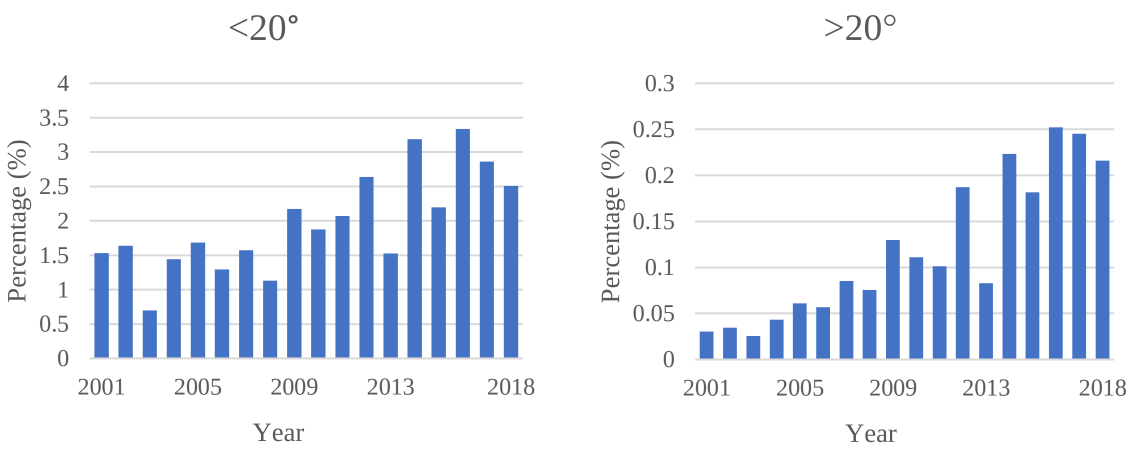

Figure 7: Annual percentage of forest loss from 2001 until 2018 for <20° slope area and >20° slope area.

3.1.4 Forest loss in protection areas

In 2000, the total forest area in the protected areas was 16 339 km², which was about 12.4 % of total forest area at that time. From 2001 until 2018, the total of forest loss in the protected areas was 852.53 km², which is about 5.2 % of the total forest area in the protection zones. More than half of the loss (544.75 km²) occurred in wildlife reserve and sanctuary areas (Figure 8). In the national parks and the forest reserves in total 120.16 km² and 5.57 km² forest were lost respectively. The temporal trend in the protection areas (Figure 9) showed forest loss peak in 2014 with 96.6 km² and after that is has decreased.

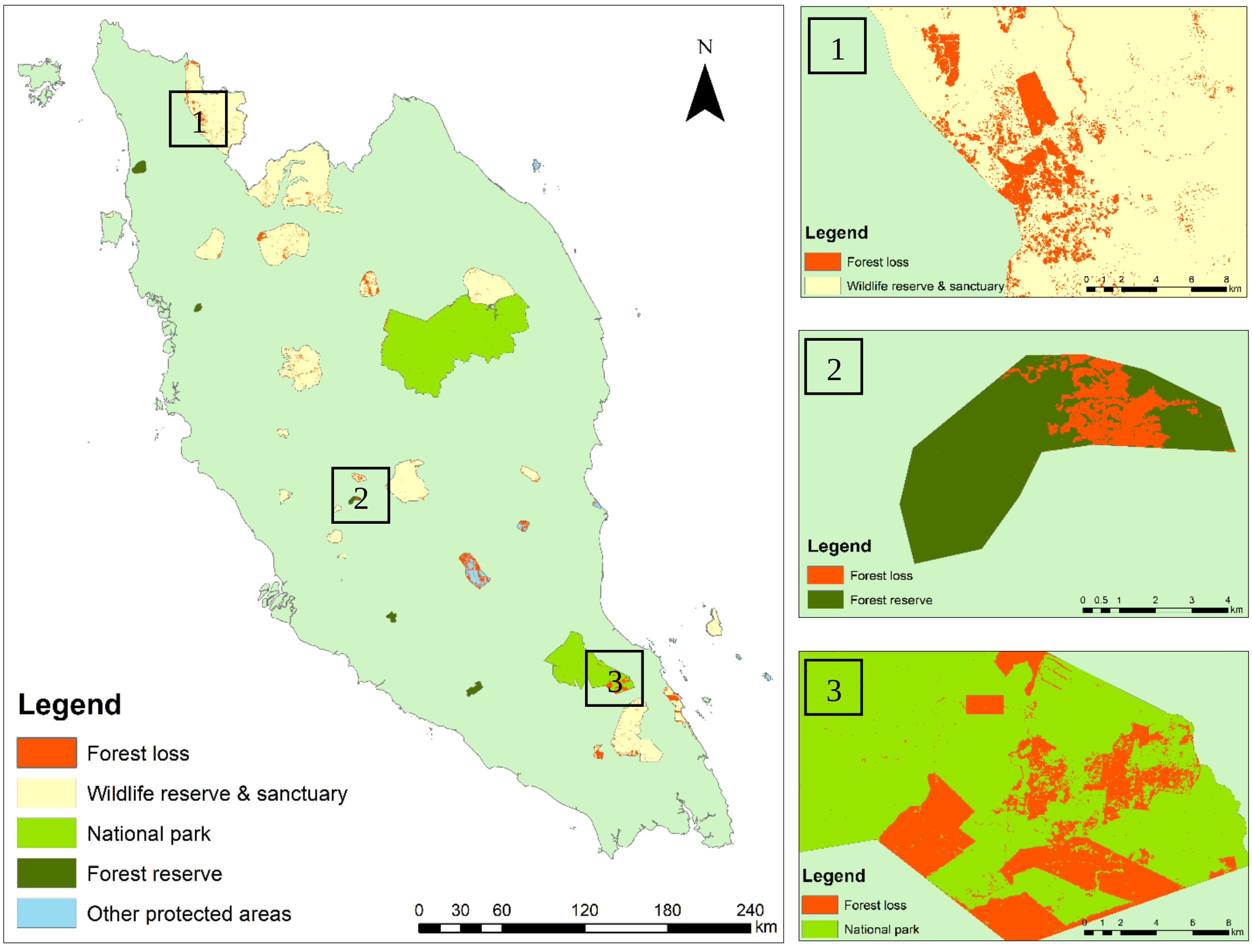

Figure 8: Forest loss in the protected areas with three sample of zoomed locations: 1) Forest loss in Ulu Muda Wildlife Reserve Park; 2) Forest loss in Bukit Kutu forest reserve; 3) Forest loss in Endau-Rompin National Park.

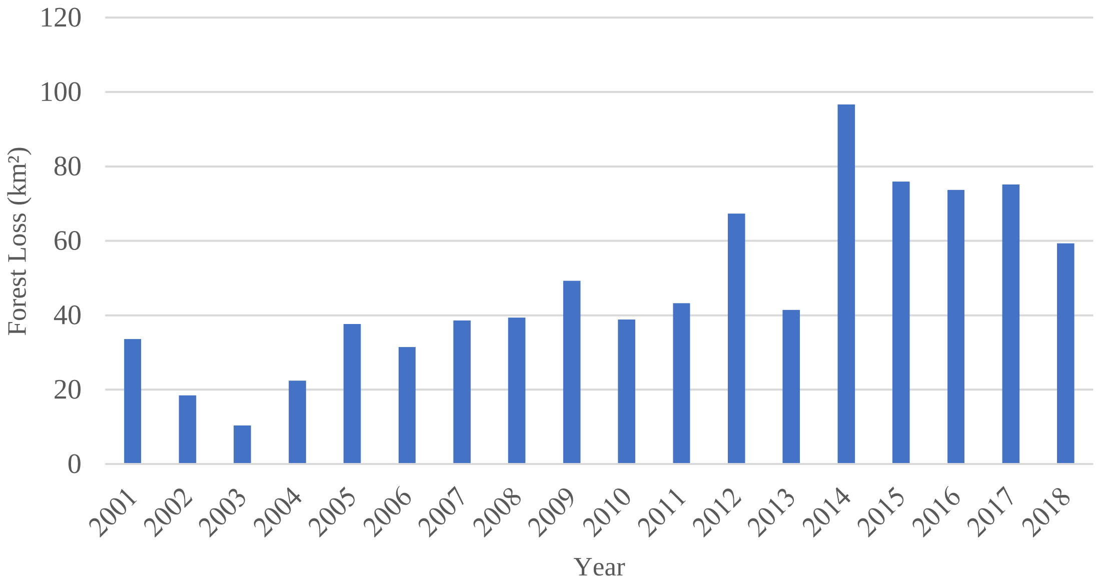

Figure 9: Temporal trends of the forest loss in the protection areas

3.2 Causes of forest loss

Figure 10 shows all the Google Earth validation samples from 62 locations in Peninsular Malaysia with zoomed examples of 5 causes of forest loss. As it shows in the first image from shifting agriculture sample located in central region, the image in 2018 shows the land is currently used as seafood farm which previously has been deforested in 2012. Based on the validation samples, the shifting agriculture areas are located in the east coast, central and southern region. The second image is Paya Peda Dam in east coast region. In this study, the construction of dam is considered as commodity-driven deforestation. The usage of Paya Peda dam is not as generating electricity but as irrigation for rice plantation in Besut and Setiu Districts, Terengganu. The dam was completed in 2015 with the size in 2018 was 17 km^2 but the forest area nearby continues losing every year since the construction of the dam.

The third image shows a palm oil plantation area in southern region. Palm oil plantation is included as commodity driven deforestation. FELDA Taib Andak Cluster, Johor is among the biggest land development area for palm oil plantation with the total size area of 102 km^2. From the map in Figure 10 the commodity-driven deforestation areas are heavily concentrated in central and southern region. The fourth image shows a forestry activity in Sik District located in west coast region. As the image in 2018, the situation shows a sign of forest growth which the place was discovered as being deforested in 2017 according to the forest loss data. Forestry activities is seemed to be happened all around the Peninsular Malaysia. The fifth image shows a new housing area in State of Selangor in central region. Housing is identified as drivers of forest loss for urbanization. The location of the image as a new housing area is reasonable because the central region of Peninsular Malaysia is known as main hub of economy in Malaysia, which also where two of Malaysia's capitals and some of largest cities in Malaysia are located. Therefore, the region attracts people around the world, thus increasing the demand for residential areas. Forest loss due to urbanization also occurred in east coast region mainly in Penang State area. This area is also known as among the most important business hubs in Peninsular Malaysia.

In general, the commodity-driven deforestation has the highest number of identified validation samples with 43, which is 69 % of the total validation samples (Figure 11). This number indicate the influence of establishment of commercial plantation in Peninsular Malaysia towards the deforestation activities. Mining and construction of dam have also led to the large scale of deforestation activities other than the palm oil plantation itself. 11 locations were experiencing forestry activities. It shows the production of timber in Peninsular Malaysia still active even though many of the forest areas have been cleared for the commercial plantation. However, most of the forestry activities do not involve a large scale of deforested area because of the forest growth which the timber still can be produced in the same area without the need of many lodging areas. Five locations from the samples was identified as urbanization. As the number of populations still growing even the growth rate is decreasing, Peninsular Malaysia are in stage of constructing many infrastructures such as residential areas, education center and mobility networks. Shifting agriculture also shows the food production which is still important in Peninsular Malaysia despite the economy of Malaysia is in the stage of changing to more industrial-based production. Lastly, from all the validation samples, there were no wildfire cases identified.

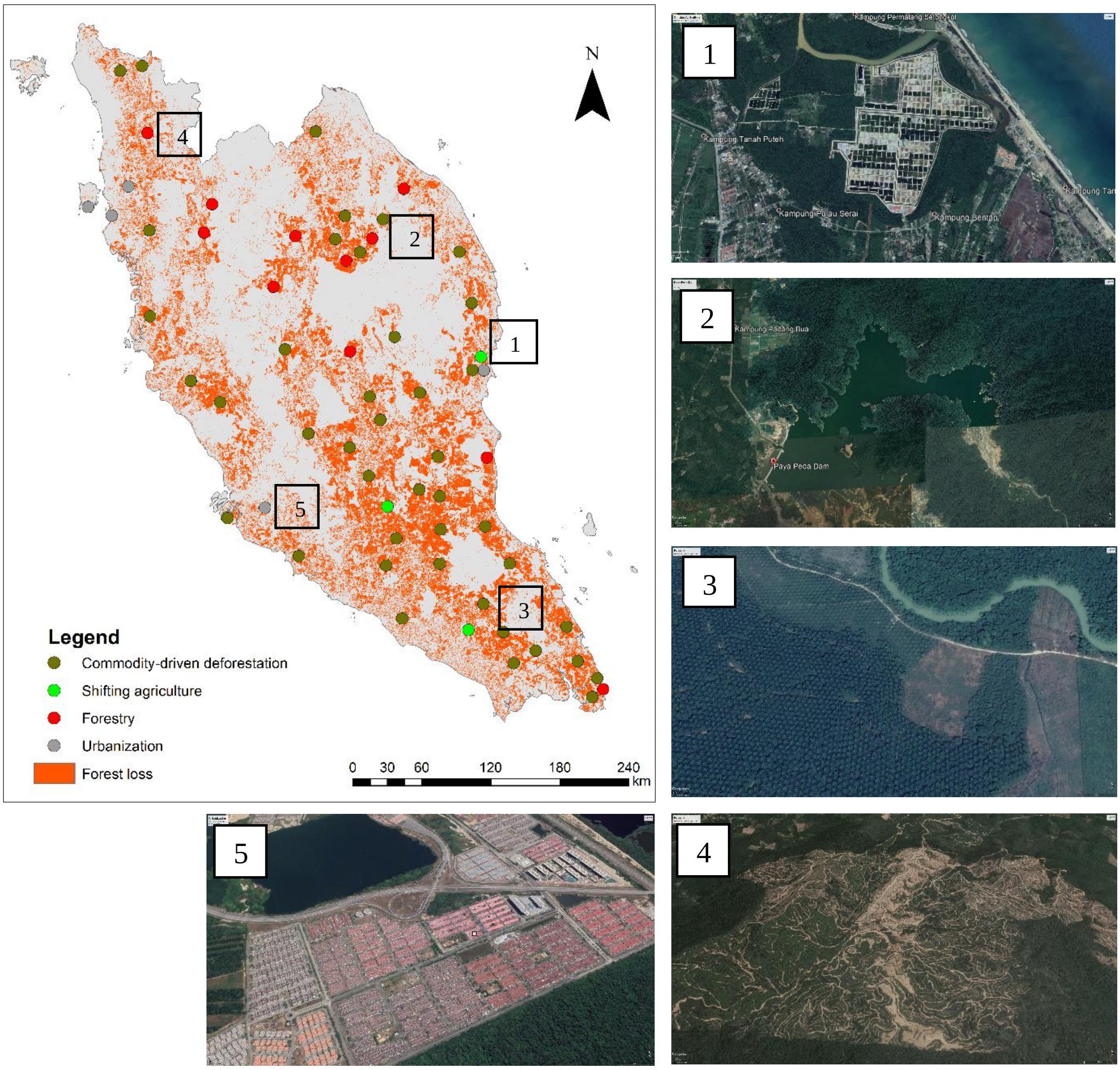

Figure 10: Locations of the forest loss drivers from 62 validation samples with 5 zoomed locations from Google Earth high-resolution imagery: 1) Seafood Farm in Pekan District. 2) Paya Peda Dam, Terengganu. 3) Commercial plantation in FELDA Taib Andak, Johor. 4) Forestry activities in Sik District. 5) New housing areas in Bandar Saujana Putra, Selangor.

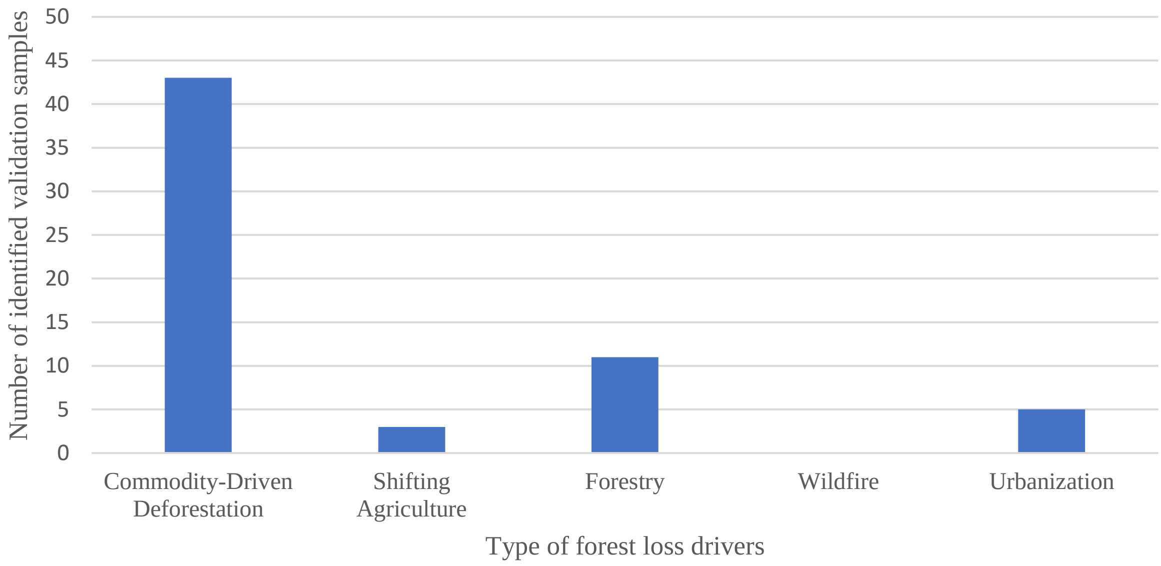

Figure 11: Type of forest loss drivers with the total number of validation samples were identified.

3.3 Hot spots of forest loss

Hot spot analysis in Figure 12 shows the location of hot spots is steadily concentrated in central, southern and east coast region while the hot spots in west coast is rather inconsistent. There is no clear temporal and spatial trend. The location of forest loss hot spots in west coast region was almost non-existent during the beginning of study period and the hot spots slowly appears in the coming years. Overall, west coast region did not experience the forest loss as other regions have and the peak of forest loss can be identified during the year of 2012 and 2013. During these years, the region had more cold spots than hot spots. The central region showed major contribution to the large scale of forest loss in Peninsular Malaysia for the whole study period compared to other regions. The southern region showed stable number of hot spots and cold spots throughout the years and most of the hot spots of forest loss located in the palm oil plantation area (Figure 13).

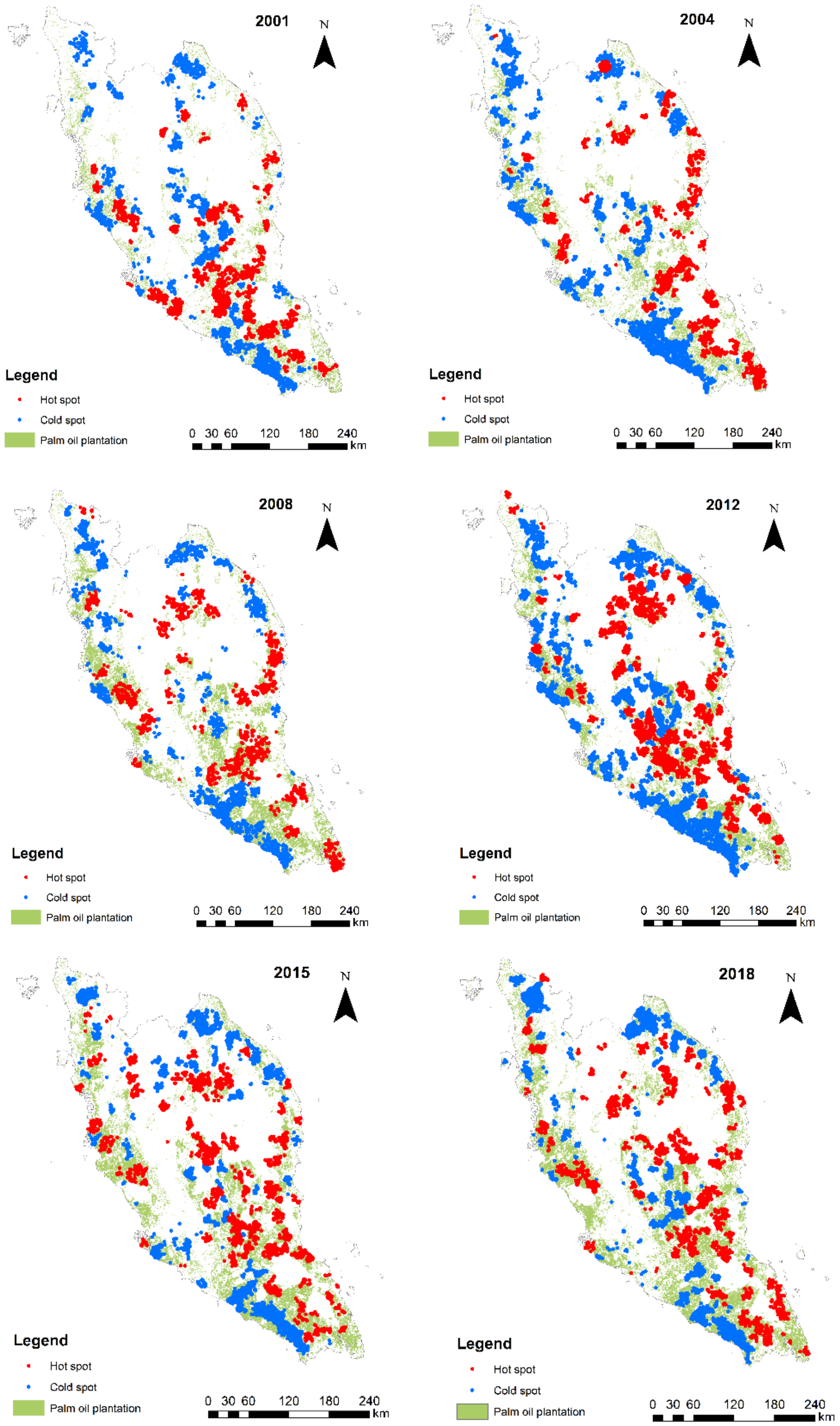

Figure 12: The results of the spatial hot spot analysis of forest loss in Peninsular Malaysia in 2001, 2004, 2008, 2012, 2015 and 2018. Hot spot represents cluster of large forest loss patches while cold spot represents cluster with small forest loss patches. Only spots with confidence interval of ≤90% are shown.

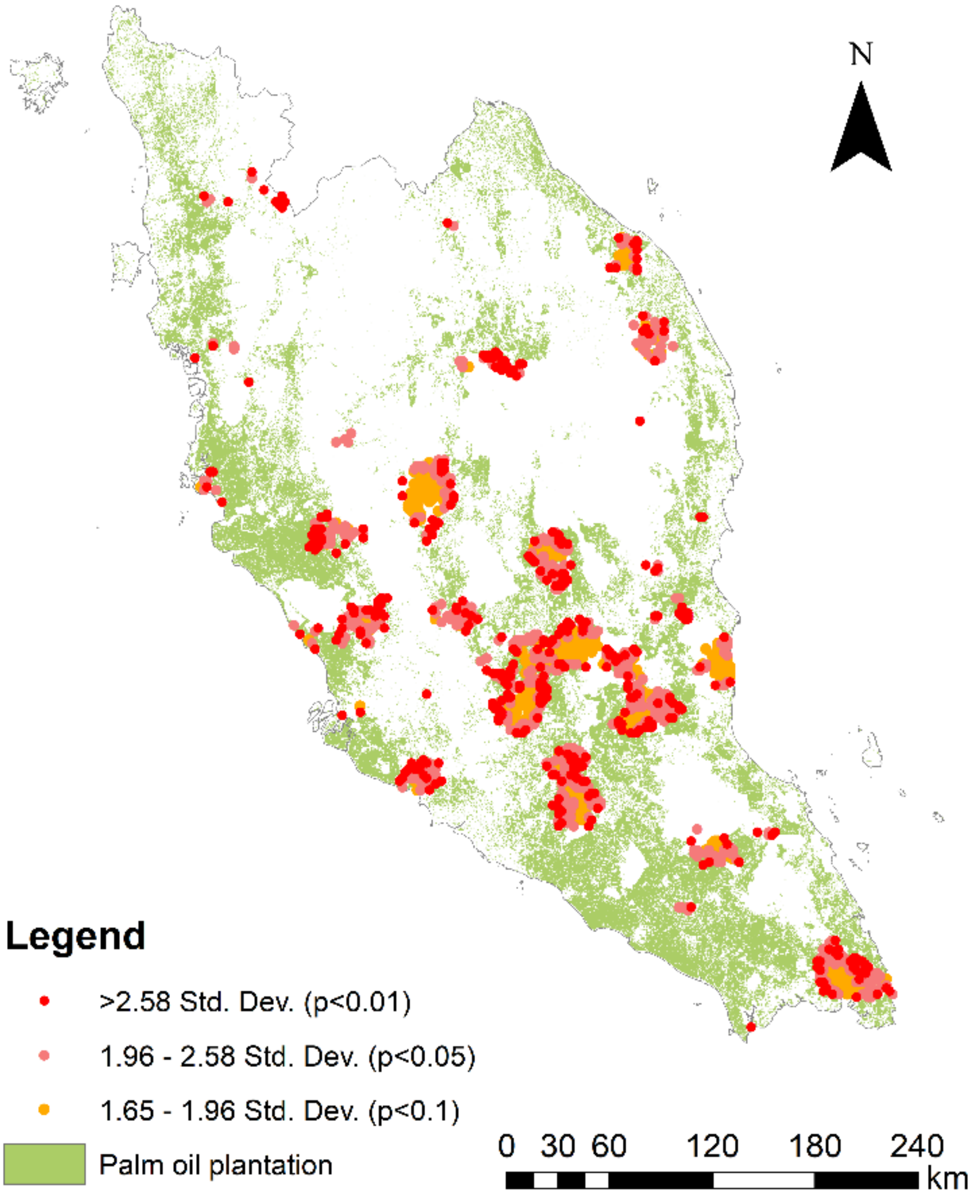

Figure 13: Hot spots of forest loss in Peninsular Malaysia based on Getis Ord Gi* z-scores for the whole study period (2001 - 2018). Higher values indicate increased clustering of deforestation patches (Z Score and associated P-value).

4. Discussion and Conclusions

In general, forest loss trends in Peninsular Malaysia were similar to those in other tropical countries such as Indonesia (Margono et al, 2014) and Madagascar (Vieilledent et al, 2018). The forest loss fluctuated but it shows an increasing trend, especially if one compares the start of the study period with the end of the study period. The total forest area is decreasing every year. The spatial distribution of the forest loss is mainly concentrated in the central and southern regions. The size of the forest loss patches is decreasing in time. Most of the forest loss has happened in the flat land area. However, the forest loss has increased in steeper slopes over the years. Protected areas also experienced forest loss during those 18 years and this is also happened in Protected Areas of Amazon in Brazil (Pfaff et al, 2015), Colombia (Clerici et al, 2020) and Mexico (Vidal, 2014). Forest area for wildlife reserve and sanctuary were the most affected protection area types in Peninsular Malaysia.

The causes of forest loss in Peninsular Malaysia are highly affected by commodity-driven deforestation, which stems from commercial plantation activities, construction of dams and mining activities. This result also was similarly achieved by Curtis et al (2018). Forestry activities are still important in Peninsular Malaysia for timber production, but the forest loss caused by forestry activities is more temporary compared to the commodity-driven deforestation, in case of which the land-use change is more permanent. Urbanization in Peninsular Malaysia does not reflect much to the forest area due to the decreasing population growth rate. However, there is still concern about building the infrastructure for citizens such as highway and railway, which can enhance the probability of growth of the deforested area. The number of land-use changes from forest to agriculture show the significant impact between the commercial plantation and food plantation. This can also be noticed as Malaysia has already achieved the status of the newly-industrialized country where the economy is heavily based on industrial production. Thus, the plantation for food production is not seen as beneficial any more in terms of economic growth compared to the commercial plantation.

Hot spots of forest loss in Peninsular Malaysia is heavily concentrated in the central and southern region. Based on the yearly and overall analysis, the west coast region does not experience many large scales of deforestation compared to other regions. This situation is also similar to the cold spots of forest loss where the southern and central regions continue to dominate the cold spots area. The hot spots in east coast had the increasing trend and dropped after that but the region still consistent in terms of small-scale deforestation.

Based on the analysis, it is revealed that the commodity-driven deforestation is a main driver causing of the forest loss. This outcome also was similar in many studies conducted by many authors (Miyamoto et al, 2014; Phua et al, 2014; Aisyah, 2016; Rahim & Shahwahid, 2014). Southern and central region of Peninsular Malaysia have more flat areas that have made them attractive for commercial plantations. Analysis dealing with the causes of forest loss shows the domination of commodity-driven deforestation where the commercial plantation is included. The result from hot spots analyses shows that most of the hot spot regions of forest loss belong mostly to the central and southern regions. By combining the results from the first analysis, it seems that the land development for commercial plantation is more approachable in the central and southern region where the slope is lower, which it makes it much better for any agricultural opportunities. This also results in the number of hot spots of forest loss being higher in the central and southern region compared to the east coast and west coast region.

Thee major causes of forest loss in Peninsular Malaysia were categorized into five different categories that include industrial logging, indirect consequences of logging, conversion of forested lands, infrastructure and urban development projects and consumer demands for logs and agriculture. The logging activities are still possible in commercial forestry areas but not for forest reserve areas and reserve land (50m buffer river buffer zone). The conversion of forested lands in Peninsular Malaysia mostly caused by the Land Development Planning Program which was designed by the federal government itself. The same has happened to the infrastructure projects for urban and development where the development of infrastructure is included in every five-year Malaysian Planning Program. The consumer demands for logs and agriculture mostly depends on the rights and the awareness of land-owners but even for a small-scale project, the approval from the state government is still required.

Deforestation in protected areas is the biggest concern that should be given special attention. Especially because the annual trends of the forest loss in the protected areas has been increasing in the recent years. It shows lack of emphasis of local authorities in Peninsular Malaysia regarding the issue of forest in conservation areas even several policies have been implemented specially to control this issue such as Wildlife Conservancy Act 2010 (Act 716) and Environmental Quality Act 1974 (Act 127). Even the Malaysian National Interpretation for the Identification of High Conservation Values (HCV) itself claims that the Malaysian National Policies do not describe conservation values along the lines of the HCV approach (HCV, 2018). This results in uncontrolled deforestation activities in the protected areas since there is no proper monitoring. This impact is similar to other tropical countries that are currently developing very fast and where the forests are thus at risk.

All these forest loss impacts are challenging to control due to various factors. At first, the national and state forest policy instruments and decision-makers arise from different levels and actors of federal and state power. Every state may outline their policy regarding the forest resources affairs but in most cases, it always results in continued contradictions with federal government's policies, enforcement and regulations. However, both state and federal government still have the same indicator, which favoured many large-scale projects such as commercial plantations and dam projects. Secondly, because of many of the existing land and forest laws are originated from British colonial times (Yong, 2015). Nowadays, these laws and policies are seemed very outdated and not applicable to today's concept. This is because the pre-independent policies are systematically ignored the customary rights of forest people over their lands and this has caused surprising situation as the policy is continuing to be implemented even during the post-independent (Yong, 2015). At last, it is also mentioned in many policy studies that ineffective and corrupt governance has caused this problem to become worse (Sundström, 2016).

The estimation of the forest loss by using remote sensing-based data is relatively precise but it has shortcomings. In the current study, afforestation was not considered due to the limitation of the data. Often enough the deforested areas will not be deforested permanently as forest fires and commercial forest where the trees will grow back to the normal height. A study from Aide et al. (2012) revealed the surprising afforestation trends in Colombia between 2001 and 2010. This situation could have happened also in Peninsular Malaysia since it shares the same climate as Colombia where the vegetation process in tropical climate goes all around the years.

The application of Google Earth to estimate the possible cause of forest loss can be precise due to the Google Earth tool has developed quickly. However, to measure the cause of forest loss in a much more specific way is rather limited. The source from Google Earth high-resolution images can be relied on but it cannot be proved statistically, other than not all images were taken by Google Earth have a similar timeline. The shifting agriculture in Malaysia only uses very small land areas for most activities which might be complicated to differentiate due to not high enough spatial resolution. Besides, many cells cannot be estimated precisely because of the poor image quality and clouds which limits the total number of valid cells to be considered.

Using remote sensing and GIS approach for monitoring forest activities is becoming more precise and practical since the technology is able to produce highly precise and usable data. The ability of various (open source) software to process the data enables to quickly analyze and visualize big amount of near-real time data and provide useful information for decision makers to improve the deforestation counter measures. In order to improve the forest monitoring using remote sensing, it would be recommended to consider forest growth, especially in tropical countries to understand better the actual total of forest area. Secondly, it would be useful to identify the exact causes of forest loss.

Summary

Master’s Thesis: Deforestation in Peninsular Malaysia from 2001 to 2018

Since the industrial revolution, forest have suffered a very big loss in their area and this phenomenon is called deforestation. Tropical forest is significantly affected by this phenomenon, which draws a lot of attentions and causes concern since tropical forest is widely known as the home for almost half of the species on earth (Monson, 2014). This research focuses on the forest loss in tropical region of Peninsular Malaysia, which has experienced a major loss during the last decades (Latif et al, 2015).

The aim of the master thesis is to estimate the deforestation in Peninsular Malaysia from 2001 to 2018. The deforestation process was explored and analyzed from three different aspects:

I. What are the general of forest loss?
II. What are the causes of the forest loss?
III. Where are the hot spot of forest loss?

The main data used for the study was been acquired from the Global Forest Change (GFC) raster dataset developed by Hansen et al (2013) from the Department of Geographical Sciences, University of Maryland using Landsat imagery. Additional datasets were also used to support the analysis of the present: Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) for estimating the slopes, protected areas dataset from International Union Conservation of Nature (IUCN).

The forest loss was analyzed for the whole study area and also by considering slope and protection areas. Potential causes of forest loss were studied by estimating cells of 62 deforested locations in Peninsular Malaysia and the change detection were categorized into five forest loss classification (Curtis et al. 2018). In addition, hot spots of forest loss were identified by using spatial statistic method from Getis-ord Gi*.

As a result, it was determined that forest loss in Peninsular Malaysia has been fluctuating but increasing from 2001 to 2018.The forest loss of patches of ≥1000ha was increased until 2014 and dropped after that which shows that the bigger scale deforestation has been decreasing after 2014. Slope analysis showed that forest loss on steeper slopes is increasing every year.

The causes of forest loss are dominated by the commodity-driven deforestation as demonstrated by performed analysis. This includes palm oil plantation activities and related infrastructure (e.g. dam construction for irrigation purposes and residential areas for the palm oil farmers). Forestry was second driver for the deforestation, followed by urbanization and shifting agriculture. The annual hot spot analysis showed that the hot spots were concentrated to the palm oil plantation areas in central and southern region where the most of palm oil plantation can be found. The establishment of palm oil plantation areas in central and southern region was also influenced by the slope where these two locations have lower slope compare to other regions.

In conclusion, it can be said that commercial plantation, mainly represented by palm oil production, was the major factor of forest loss in Peninsular Malaysia from 2001 to 2018.

Kokkuvõte

Magistritöö: Metsade kadu Malaka poolsaare lõunaosas aastatel 2001 kuni 2018

Alates tööstusrevolutsioonist on metsakadu maailmas olnud väga suur, mis on seadnud ohtu liigilise mitmekesisuse (Monson. 2014). Käesolev uurimistöö keskendub metsade muutustele ja kaole troopilises piirkonnas, kuna sealsest piirkonnast on viimastest kümnenditest alates kadunud suurtes kogustes metsa (Latif et al. 2015).

Käesoleva magistritöö eesmärgiks on analüüsida metsade kadu Malaka poolsaare lõunaosas aastatel 2001 kuni 2018. Töö käigus püstitati kolm uurimisküsimust:

I. Millised on metsade kadumise üldised trendid?
II. Millised on metsade kadumise põhjused?
III. Millised on metsade kadumise tulipunktid?

Uurimistööks kasutati Marylandi Ülikooli poolt Landsati piltide põhjal välja töötatud metsade muutuste andmestikku (Global Forest Change –GFC). Lisaks SRTM kõrgusmudelit nõlvakallete hindamiseks ning Rahvusvahelise Looduskaitseliidu (IUCN) kaitsealade andmestikku.

Metsade kadu analüüsiti kogu uurimisala ulatuses ning ka arvestades poolsaare reljeefi ja kaitsealasid. Metsade kao võimalikke põhjuseid hinnati 62 detailsemal uurimisalal ning metsade kao põhjused klassifitseeriti viide klassi Curtis et al. (2018) järgi. Lisaks tuvastati Getis-ord Gi * statistiku abil metsade kao tulipunktid.

Töö tulemustest selgus, et metsade kadu on aastati olnud väga kõikuv, kuid siiski olulise kasvutrendiga. Suurte raielankude arv kasvas kuni 2014. aastani ja on sellest ajast alates langenud. Samas on väiksemate metsakao eraldiste arv kasvanud. Viimastel aastatel on ka kasvutrendis järsumatel nõlvadel metsade raie. Ühtlasi tuvastati vähesel määral metsade kadu kaitsealadest.

Peamiste metsa kao põhjustena tuvastati õlipalmi istanduste rajamine ning sellega seotud infrastruktuuri rajamine (nt tammi rajamine palmiistanduste niisutamiseks ja palmiõli tootjate elamupiirkonnad). Tähtsuselt järgmiseks põhjuseks on metsandus, millele omakorda järgnevad linnastumine ja muutused põllumajanduses. Tulipunktide analüüs tuvastas peamised suuremad metsaraie alad õlipalmi istanduste alades uurimisala kesk- ja lõunaosas. Palmiõlikasvanduste rajamise kesk- ja lõunaregioonis tingis muuhulgas ka nõlvade kuju, sest neis piirkondades on nõlvad teiste piirkondadega võrreldes laugjamad.

Kokkuvõtteks võib öelda, et õlipalmi istandused on olnud Malaisia poolsaare metsade kaotuse peamine tegur aastatel 2001–2018.

ACKNOWLEDGEMENTS

I would like to acknowledge my supervisors, Dr. Evelyn Uuemaa and Bruno Montibeller (MSc) for providing guidance and support throughout the process of writing this thesis. Without their time and commitment to always help me, I would not have been able to finish this thesis. Special thanks also go to my family and friends in Malaysia and Estonia, my course mates in MSc. Geoinformatics for Urbanised Society program and all stuff from the Department of Geography, University of Tartu for their continuous contribution and encouragement.

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