Deforestation and reforestation analysis from land-use changes in North Sumatran Mangroves, 1990-2015

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Abstract. Mangrove forest plays a critical role in the context of climate change in tropical and subtropical regions. The present study analyzed the deforestation and reforestation from land-use and land-cover changes from 1990, 2000, 2009 and 2015 in North Sumatran mangrove forest, Indonesia. The land-use/land-cover consists of thirteen classes namely, primary mangrove forest, secondary mangrove forest, shrub, swamp shrub, swamp, settlement, paddy field, oil palm plantation, aquaculture, dry land farming, mixed dry land farming, mining, and barren land. Results showed that primary mangrove forests significantly decreased 61.21% from 1990 to 2015, mostly deforestation was derived from 1990 to 2000 to be secondary mangrove forest and swamp shrub. During 25 years observed, no reforestation was noted in the primary mangrove forest. Similarly, secondary mangrove forest had been degraded from 56,128.75 ha in 1990 to only 35,768.48 ha in 2015. Drivers of deforestation found in secondary mangrove forests were aquaculture (43.32%), barren land (32.56%), swamp shrub (10.88%), and oil palm plantation (5.17%). On the other hand, reforested activity was occurred only 701.83 ha from 1990 to 2015, while the nonforest use has been increased. These data are likely to contribute towards coastal management planning, conservation, and rehabilitation of degraded mangrove forests.

1. Introduction
Mangrove forests are widespread in the inter-tidal zone of tropical and sub-tropical climates and play a significant role in the context of climate change in the regions. Given their ecological, economic, and environmental significance, mangroves are currently the most threatened ecosystems due to indirect and direct deforestation and degradation [1]. Aquaculture and oil palm estate have been major drivers of mangrove loss in Indonesia [2-3]. Deforestation negatively impacted on 16% of global mangrove species under risk of extinction [4] and reduced mangrove biodiversity and carbon storage of forest biomass [3,5]. Mangrove conservations as well as sustainable mangrove management, therefore, are needed to maintain the presence of mangrove forest and increased reforestation programs.

In spite of mangrove deforestation globally or regionally was well documented [1,3], deforestation and reforestation as well from land-use and land-cover changes are rarely reported especially at regency level in Indonesia. To get more insight into a better understanding of spatial and temporal variation in the land uses that in displacing mangrove forests, the present study aimed to analyze the drivers of mangrove loss and reforested mangrove from land-use and land-cover changes from 1990, 2000, 2009 and 2015 in North Sumatran mangrove forest, Indonesia.
2. Materials and Method

2.1. Study area and dataset
The study was carried out in North Sumatran mangrove forest, Indonesia, where primary and secondary mangrove distributed naturally in 13 Regencies of North Sumatra province. These regencies namely Asahan, Batubara, Gunung Sitoli, Medan city, South Nias, North Nias, Central Tapanuli, Serdang Bedagai, Labuhanbatu, Deli Serdang, Langkat, Mandailing Natal, and North Labuhanbatu (Figure 1). Land-use and land-cover changes data period 1990-2015 was obtained from Ministry of Forestry, Government of Indonesia. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite image was acquired from USGS (http://govis.usgs.gov/).

2.2. Analysis of land-use and land-cover changes
Analysis of the Landsat images was carried out by applying supervised classification with maximum likelihood as previously reported [2,6]. Image pre-processing, the process of image interpretation, image classification and change detections were done by ArcGIS 9.3.1 and ArcView 3.3. The ground check was conducted by utilizing Global Positioning System (GPS) to collect information of recent land use/land-cover. The information was used as guidance for image geometric correction and image rectification.

2.3. Analysis of deforestation rate of North Sumatran mangrove
Primary and secondary mangroves existed in 13 regencies in North Sumatra as previously described. Deforestation rate was measured from total mangrove loss (primary and secondary) from the year 2015 to the year 1990. From this measurement, annual deforestation, deforestation proportion, and class of deforestation were determined.

Figure 1. Location of study area showing primary and secondary mangrove forest in North Sumatra

3. Results and Discussion
The results will be discussed in two subsections; they are land-use/land-cover changes between 1990 and 2015 and deforestation and reforestation implication in North Sumatran mangrove.

3.1. Land-use/land-cover changes between 1990 and 2015
Mangrove deforestation remains huge in North Sumatra with more than 22,513.2 ha mangrove lost between 1990 and 2015 (Figure 2). Figure 2 depicts that primary mangrove forests significantly
decreased 61.21% from 1990 to 2015, mostly deforestation was derived from 1990 to 2000 to be secondary mangrove forest and swamp shrub. During 25 years observed, no reforestation was noted in the primary mangrove forest. The land-use/land-cover changes in North Sumatran mangrove over period 1990-2015 are shown in Tables 1-2. The land-use/land-cover consists of thirteen classes namely, primary mangrove forest, secondary mangrove forest, shrub, swamp bush, swamp, settlement, paddy field, oil palm plantation, aquaculture, dry land farming, mixed dry land farming, mining, and barren land.

There were four main displacing mangrove land use types identified in the primary forest from the largest area to fewer one: secondary mangrove forest, swamp shrub, barren land, and aquaculture (Table 1). Similarly, secondary mangrove forest has been degraded from 56,128.75 ha in 1990 to only 35,768.48 ha in 2015 (Figure 2). As displayed in Table 2, there are four primary drivers of deforestation found in secondary mangrove forests were aquaculture (43.32%), barren land (32.56%), swamp shrub (10.88%), and oil palm plantation (5.17%).

![Graph](image)

**Figure 2.** Trend of mangrove deforestation in North Sumatran mangroves over 1990-2015

**Table 1.** Deforested primary mangrove forest 1990-2015 converted to different land uses

| Land-use (1990)        | Land-use (2015) | Area (ha) | Proportion (%) |
|------------------------|-----------------|-----------|----------------|
| Primary mangrove forest| Shrub           | 30.9      | 1.4            |
|                        | Barren land     | 366.1     | 17.0           |
|                        | Secondary mangrove | 1,142.8 | 53.1           |
|                        | Swamp shrub     | 445.9     | 20.7           |
|                        | Dryland farming | 1.8       | 0.1            |
|                        | Aquaculture     | 165.5     | 7.7            |
| Total                  |                 | 2,152.9   | 100.0          |

Other factors, such as agricultural expansion (dryland and mixed dryland), mining, and settlement, are also responsible for deforestation in the secondary mangrove in North Sumatra. By contrast to this study and in Indonesian mangrove was described [3]. Mangrove conversion to agriculture expansion
as major causes of deforestation in some Asia countries such as Thailand (50%), Myanmar (98%), Malaysia (43%), Bangladesh (77%), India (50%), and Sri Lanka (92%) [3].

Table 2. Deforested secondary mangrove from 1990-2015 converted to other land uses

| Land-use (1990)        | Land-use (2015) | Area (ha) | Proportion (%) |
|------------------------|-----------------|-----------|----------------|
| Secondary mangrove forest | Shrub           | 141.3     | 0.6            |
|                        | Oil palm plantation | 1,149.0   | 5.2            |
|                        | Settlement      | 37.1      | 0.2            |
|                        | Barren land     | 7,228.9   | 32.6           |
|                        | Swamp shrub     | 2,416.5   | 10.9           |
|                        | Dryland farming | 803.1     | 3.6            |
|                        | Mixed dryland farming | 765.0     | 3.4            |
|                        | Paddy field     | 26.8      | 0.1            |
|                        | Aquaculture     | 9,619.6   | 43.3           |
|                        | Mining          | 8.3       | 0.0            |
| **Total**              | **Swamp**       | **9.4**   | **0.0**        |

Figure 3. Deforestation rate in North Sumatran mangrove over period 1990-2015

3.2. Deforestation and reforestation analysis

Figure 3 shows percentage mangrove deforestation in North Sumatra between 1990 and 2015 was classified into 4 group, the first group with deforestation rate less than 1 % occurred in Asahan, Batubara, Gunung Sitoli, Medan, South Nias, North Nias, and Central Nias. The second group of 1-2 %, where deforestation occurred in Serdang Bedagai, Labuhanbatu, and Deli Serdang. The third
A group of 2-3% deforestation rate was in Langkat and Mandailing Natal. The last group with more than 3% deforestation rate was only in North Labuhanbatu.

Furthermore, the deforestation occurred in North Sumatra was 900.5 ha/year with percentage rate was 1.2%. The highest deforestation rate was in Langkat (719.1 ha/year), while the lowest in South Nias (0.11 ha/year). The present result supported the previous report on the drivers of mangrove deforestation in Langkat mostly that mangrove conversion into aquaculture ponds (50%) and oil palm plantation (28.8%) is one of the primary reasons for such high rates of deforestation [2]. Oil palm plantation also contributed to mangrove deforestation in North Sumatra. The threat of oil palm to mangrove is likely to increase in future [1]. Furthermore, it has been reported that mangrove deforestation between 2000 and 2012 in the east coast of Sumatra around 500-1000 ha/ha [1]. Indonesian mangrove, however, has percentage mangrove loss was 1.7% [1], slightly similar to this study (1.5%). Mangrove conversion to aquaculture also has been reported in Kalimantan and Sulawesi [1]. Our study and other studies suggested that aquacultures are responsible for the significant part of mangrove deforestation.

Table 3. Reforested secondary mangrove from 1990-2015

| Land-use (1990) | Land-use (2015) | Area (ha) | Proportion (%) |
|----------------|----------------|-----------|----------------|
| Barren land    | Secondary mangrove | 219.2 | 31.2 |
| Water body     | Secondary mangrove | 126.6 | 18.0 |
| Swamp shrub    | Secondary mangrove | 211.5 | 30.1 |
| Dryland farming| Secondary mangrove | 15.5 | 2.2 |
| Aquaculture    | Secondary mangrove | 129.1 | 18.4 |
| Total          |                 | 701.8    | 100.0 |

Reforestation activity was observed in this study and occurred in secondary mangrove only as 701.83 ha from 1990 to 2015, while the nonforest has been increased (Table 3). The main land uses to be reforested barren land (219.2 ha), swamp shrub (211.5 ha), aquaculture (129.1), and water body (126.6 ha). Rehabilitation on degraded mangrove was proposed with some considerations such as extent, accessibility, and socioeconomic factors of a local community to get successful mangrove regrowth [3]. Mangrove rehabilitation is significant efforts to restore within the framework of regional development. The rehabilitation program is proposed by the involvement of the local communities dependent on the mangrove ecosystem for sustenance [7]. Recently it has been reported that to reduce global emission from mangrove loss for a cost at less than $10 to $15 CO₂ [5]. Parallel with this finding, the primary threats to all mangrove species are habitat degradation and mangrove area for conversion to aquaculture, agriculture, urban and coastal development, and overexploitation [4]. Thus, nowadays social induced-rapid developmental changes stipulate a better understanding of the dynamic of mangrove forest [8].

4. Conclusions
Primary drivers of deforestation in North Sumatran mangrove, especially from secondary mangrove forest was derived from land-use of aquaculture. Conservation and reforestation of mangrove forest should be the principal target in North Sumatra. The present data are likely to contribute towards coastal management planning, conservation, and rehabilitation of degraded mangrove forests in North Sumatra.

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