Deforestation trend in North Sumatra over 1990-2015

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Abstract. Deforestation and forest degradation have been previously reported to contributing greenhouse gas emission, the primary driver of global warming. The present paper studies deforestation and reforestation trend in North Sumatra, Indonesia using land-use/land-cover change from 1990-2015. The land-use consists of three classes derived from forest land (primary and secondary dry land forest, primary and secondary swamp forest, primary and secondary mangrove forest). Non-Forest (shrub, oil palm plantation, forest plantation, settlement, barren land, swamp shrub, dry land farming, mixed dry land farming, paddy field, aquaculture, airport, transmigration, and mining), and water body (water and swamp). Results showed that from 33 regencies/city in North Sumatra, among them, 25 districts deforested, which was the highest deforestation rate in Labuhanbatu and South Labuhanbatu (2,238.08 and 1,652.55 ha/year, respectively), only one area reforested, and seven districts showed no deforestation or reforestation. During 25 years observed, the forest has been deforested 22.92%, while nonforest has been increased 11.33% of land-use. The significant increasing loss of North Sumatran forest implies conservation efforts and developing sustainable forest management.

1. Introduction
Indonesian tropical rain forest contributes the highest annual deforestation among the tropical countries [1]. Deforestation denotes as the permanent conversion of forest to another land-use while degradation shows that forests remain forests but lose their ability to support ecosystem services [2]. The deforestation led to increased green house gas, biodiversity loss, and net biomass carbon loss [1-4]. The deforestation accounts about 90% net emission including shifting cultivation and degradation for about 10%, mostly derived from logging (with regrowth) for industrial and fuel wood [2]. Conversion forest to cropland, pasture, the draining and burning of peat land, have become the forces driving of deforestation in the tropic [2].

Based on Landsat data Indonesia has been reported to increase in forest loss (1021 km².year⁻¹), with a little of under 10,000 km².year⁻¹ from 2000-2003 and a high of over 20,000 km².year⁻¹ in 2011 to 2012 [5]. Peat swamp forests converted to oil palm plantation resulted to biodiversity reduces of 1% in Borneo (4 species), 3.4% in Sumatra (16 species), and 12.1% in Peninsula Malaysia (46 species) [4]. Forest conservations as well as sustainable forest management, therefore, are needed to maintain the presence of primary and secondary dry land, mangrove, and peat land forest and to increase reforestation programs.

Deforestation was globally or regionally well-documented [1,2,4,5], nonetheless, deforestation and reforestation as well from land-use and land-cover changes have not been previously reported primarily 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 forests, the present study aimed to describe the
drivers of forest loss and reforested from land-use and land-cover changes from 1990, 2000, 2009 and 2015 in 23 regencies of North Sumatran forest, Indonesia.

2. Materials and methods

2.1. Study area and dataset
The study was carried out in North Sumatran forest, Indonesia, where the land-use and land cover consist of three classes derived from forest land (primary and secondary dry land forest, primary and secondary swamp forest, primary and secondary mangrove forest). Non-forest (shrub, oil palm plantation, forest plantation, settlement, barren land, swamp forest, dry land farming, paddy field, aquaculture, airport, transmigration, and mining), and water body (water and swamp). The land-use distributed in 23 Regencies/cities of North Sumatra province, namely Asahan, Batubara, Dairi, Deli Serdang, Gunung Sitoli, Humbang Hasundutan, Karo, Binjai city, Medan city, Tanjungbalai city, Labuhanbatu, South Labuhanbatu, North Labuhanbatu. Next are Langkat, Mandailing Natal, Nias, West Nias, South Nias, North Nias, Padang Lawas, North Padang Lawas, Padangsidimpuan, West Pakpak, Pematangsiantar, Samosir, Serdang Bedagai, Sibolga, Simalungun, South Tapanuli, Central Tapanuli, North Tapanuli, Tebingtinggi and Toba Samosir (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/).

![Figure 1. Location of study area showing land-use including forest, non-forest, and water body in North Sumatra](image)

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 [3,6]. Image pre-processing, the process of image interpretation, image classification and change detections were done by ArcGIS 9.3.1 and ArcView 3.3 as previously reported [3,6]. The information was used as guidance for image geometric correction and image rectification.

2.3. Analysis of deforestation rate of North Sumatran mangrove
Three classes of land-use/land-cover changes namely forest land, nonforest land, and water body existed in 33 regencies/cities in North Sumatra as previously described [3]. The term of plantation/regrowth land-use class, such as plantation forest was not consideration as a forest land...
cover class as previously reported [6-7]. Deforestation rate was measured from total forest loss (primary and secondary dry land, mangrove, and swamp) from the year 1990 to the year 2015. From this measurement, annual deforestation, deforestation proportion and rate, and class of deforestation were determined.

3. Results and discussion

3.1. Land-use/land-cover changes between 1990 and 2015

Figure 2 shows the deforestation trend in North Sumatra over 1990-2015. Forest land occupied 2,322,770.86 ha in 1990 but/and in 2015 has been lost 1,790,425.30 ha. On the other hand, forest cover was 32.79% in 1990 to be 25.27% in 2015 (Table 1). In contrast to this observation, Non-forest land increased significantly from 4,716,416.42 ha in 1990 to 5,250,676.66 ha in 2015 covered 74.11% of land-use in North Sumatra.

Deforestation remains huge in North Sumatra with more than 595,220.57 ha primary and secondary forest (dry land, mangrove, and swamp) lost between 1990 and 2015 (Figure 2, Table 2). Furthermore, reforestation occurred 34,347.06 ha, less than 10% of deforestation area during 25 years observed. The nonforest land-use tend to increase with time, no change of water body land-use, however, forest land-use seems to decrease during 1990-2015 in North Sumatra (Figure 2). Water body might play an important role in the reforestation activity in North Sumatra, conversion from water body to be secondary mangrove forest [3].

Figure 2. Trend of deforestation in North Sumatran forest, non-forest, and water body over 1990-2015

Several studies have reported drivers of deforestation in Indonesia [7-8]. Fiber plantation and logging concessions are responsible for the largest forest loss (~1.9 million ha and ~1.8Mha, respectively) in Kalimantan, Sumatra, Papua, Sulawesi, and the Moluccas during 2000-2010 [7]. Oil palm industry was ranked third as driver deforestation (~1 Mha) in this study, contributing the second leading source of carbondioxide emissions (~1,300 – 2,350 Mt CO₂) [7]. Oil palm plantation in Kalimantan alone has been reported to release 18-22% equal to 0.12-0.15 GtC/year of Indonesian’s 2020 carbon dioxide equivalents emissions [8].

Table 2 depicts the deforestation and reforestation from land-cover changes 1990-2015 in North Sumatra. The largest deforestation has displayed the regency of North Sumatra province: South Labuhanbatu, Labuhanbatu, North Padang Lawas, Serdang Bedagai, and Asahan. In South Labuhanbatu, the main land-use changes occurred in forest lands: secondary dry land forest was 38,575.79 ha in 1990 decreased to 1,570.79 ha in 2015, whereas secondary swamp forest 4,308.67 ha
in 1990 reduced to 0 ha in 2015. In contrast, barren land was 1,945.11 ha in 1990 significantly enhanced 100,693.66 ha in 2015. Main driver deforestation in South Labuhanbatu derived from the degraded land of barren land.

In Labuhan Batu Regency source of deforestation from land-use changes were secondary dry land forest, secondary swamp forest, and primary mangrove forest. The secondary dry land forest had been deforested from 15,634.20 ha in 1990 to 0 ha in 2015. Similarly, secondary swamp forest was 42,063.06 ha in 1990 had lost to 1,606.14 ha in 2015. Labuhanbatu was also lost primary mangrove forest 52.63 ha during 1990-2015. Besides, deforestation in North Padang Lawas was mainly from secondary dry land forest: 84,274.78 ha in 1990 to 21,691.18 ha in 2015 (Table 2).

Furthermore, the source of deforestation in Serdang Bedagai district came from land-use changes of secondary dry land forest and secondary mangrove forest to other land-use. Both forest lands have been deforested significantly, land-use of secondary dry land forest 1,839.79 ha in 1990 lost to 633.42 ha in 2015. Secondary mangrove forest-cover decreased in 1990 of 299.18 ha to 16.26 ha in 2015. In Asahan district, the decreasing secondary dry land forest from 34,333.75 ha to 32,619.06 ha during 1990-2015. It is noteworthy that oil palm plantation increased significantly in North Padang Lawas, Langkat, and Asahan districts. In North Padang Lawas, oil palm plantation area was 79,464.64 ha in 1990, enhanced to 92,426.36 ha in 2015. Similar results in Langkat and Asahan, oil palm industry, increased significantly from 97,408.63 and 114,599.44 ha to 152,302.46 and 154,250.28 ha, respectively during 25 years observed.

### Table 1. Percentage of Land-use change period 1990, 2000, 2009, and 2015

| Land-use         | 1990  | 2000  | 2009  | 2015  |
|------------------|-------|-------|-------|-------|
| Forest           | 32.79 | 29.22 | 27.13 | 25.27 |
| Non-forest       | 66.57 | 70.13 | 72.25 | 74.11 |
| Water body       | 0.64  | 0.65  | 0.62  | 0.62  |
| Total            | 100.00| 100.00| 100.00| 100.00|

Forest land: primary and secondary dry land forest, primary and secondary swamp forest, primary and secondary mangrove forest. Non-forest: shrub, oil palm plantation, forest plantation, settlement, barren land, swamp shrub, dry land farming, mixed dry land farming, paddy field, aquaculture, airport, transmigration, and mining. Water body: water and swamp.

3.2. Deforestation and reforestation analysis

Table 2 displays deforestation and reforestation from land cover change 1990-2015. Figure 3 shows the percentage of mangrove deforestation in North Sumatra between 1990 and 2015 was classified into six groups, the first group with negative deforestation rate occurred in only in Humbang Hasundutan. The second group without deforestation due to no forest land covered, such as in Binjai city, West Nias, Tanjung Balai city, Padang Sidempuan, Pematang Siantar, Sibolga, and Tebingtinggi. The third group contained less than 1% deforestation rate, occurred in majority study sites, Batubara, Dairi, Deli Serdang, Gunung Sitoli, Karo, Medan, Langkat, South Nias, West Pakpak, Simalungun, South Tapanuli, North Tapanuli, Simalungun, and Toba Samosir. The fourth group of 1-2 %, were deforested in Asahan, North Labuhanbatu, Mandailing Natal, Nias, North Nias, Central Tapanuli, Padang Lawas, and Samosir. The fifth group of 2-3% deforestation rate was in North Padang Lawas and Serdang Badagai. The last group with more than 3% deforestation rate was in Labuhanbatu and South Labuhan Batu.
### Table 2. Deforestation and reforestation from land cover changes 1990-2015

| Regency/city          | Land-cover changes 1990-2015 (ha) | Def (year/ha) | Def rate (%) |
|-----------------------|-----------------------------------|---------------|--------------|
|                       | Def | Ref | Forest | NF | WB |               |               |
| Asahan                | 30,567.21 | - | 38,019.33 | 306,193.69 | 2531.09 | 1,222.69 | 1.78 |
| Batubara              | 16.06 | - | 676.27 | 89,885.91 | 538.01 | 0.64 | 0.09 |
| Dairi                 | 7605.35 | - | 51,301.19 | 139,154.16 | 67.26 | 304.21 | 0.52 |
| Deli Serdang         | 2,060.93 | 56.93 | 20,475.35 | 234,696.57 | 1,031.88 | 80.16 | 0.36 |
| Gunungsitoli          | 15.02 | - | 135.56 | 30,886.54 | 46.03 | 0.60 | 0.40 |
| Humbang Hasundutan    | 15,513.15 | 24,897.37 | 74,047.99 | 138,230.57 | 269.02 | -357.37 | -0.42 |
| Asahan                | 1,444.09 | 0.00 | 59,674.25 | 152,830.88 | 171.17 | 57.76 | 0.09 |
| Batubara              | 114.77 | - | 589.75 | 27,150.24 | 419.21 | 4.59 | 0.65 |
| Dairi                 | - | - | 9,413.74 | - | - | - | - |
| Deli Serdang         | 55,951.91 | - | 206,647.33 | 5,325.48 | 469.03 | 3.70 |
| Gunungsitoli          | 41,313.33 | - | 262,959.77 | 1,231.38 | 1,652.55 | 3.85 |
| Humbang Hasundutan    | 35,023.33 | - | 24,124.37 | 1,570.79 | 261.80 | 1.86 |
| Asahan                | 1,937.77 | 0.00 | 77,572.79 | 22.13 | 77.51 | 1.24 |
| Batubara              | - | - | 47,297.60 | 129.26 | - | - | - |
| Dairi                 | 6,544.18 | - | 100,090.41 | 675.95 | 261.77 | 0.25 |
| Deli Serdang         | 2,231.25 | 0.00 | 111,168.02 | 513.76 | 3,228.10 | 1.87 |
| Gunungsitoli          | 120,831.78 | 1,954.93 | 289,161.40 | 1,292.01 | 4,755.07 | 1.16 |
| Humbang Hasundutan    | 32,932.58 | 505.63 | 214,323.19 | 367,090.50 | 675.59 | 261.77 | 1.86 |
| Asahan                | 1,314.01 | - | 189,842.94 | 52.56 | 52.56 | 2.42 |
| Batubara              | 1,061.18 | - | 7,684.02 | - | - | - | - |
| Dairi                 | 8,163.94 | 651.90 | 89,290.72 | 575.81 | 1.75 |
| Deli Serdang         | 1,314.01 | - | 189,842.94 | 52.56 | 52.56 | 2.42 |
| Humbang Hasundutan    | 81,142.50 | 439.97 | 200,054.29 | 531.76 | 3,228.10 | 1.87 |
| Asahan                | 3,894.09 | - | 95.84 | - | - | - | - |
| Batubara              | 3,085.66 | 62,726.59 | 147,913.17 | 678.16 | 1.08 |
| Dairi                 | 3,894.09 | - | 95.84 | - | - | - | - |
| Deli Serdang         | 3,085.66 | - | 62,726.59 | 147,913.17 | 678.16 | 0.19 |
| Humbang Hasundutan    | 595,220.57 | 34,347.06 | 1,621,684.08 | 4,798,768.65 | 34,686.92 | - | - |

Def: Deforestation, Ref: Reforestation, NF: Non-forest, WB: Water body, -: not available
Furthermore, during 1990-2015 the deforestation occurred in North Sumatra was 23,808.82 ha.year\(^{-1}\) with percentage rate was 1.06 %. The highest deforestation was in Mandailing Natal 4,755.07 ha.year\(^{-1}\), however, in this regency reforested 1,954.93 ha.year\(^{-1}\) period 1990-2015 and grouped into the fourth category. By contrast, Labuhanbatu and South Labuhanbatu showed lower deforestation 2,238.08 and 1,652.55 ha, respectively. However, during study observed, no reforestation occurred (Table 2). The high deforestation in this province implies to increase conservation efforts and reforestation thoroughly the North Sumatra province.

The present study indicated the increasing plantation estates were from 999,596.12 ha in 1990 to 1,233,929.56 ha in 2015. The developing area of estate land was 9,373.33 ha.year\(^{-1}\). In this context, oil palm industry contributed to deforestation in North Sumatra was 39.37%. Major increased area of oil palm industry derived from the conversion of forest land (Table 2).

Oil palm plantation also contributed to mangrove deforestation in North Sumatra [3]. The threat of oil palm to mangrove is likely to increase in future [9]. Furthermore, it has been reported that mangrove deforestation between 2000 and 2012 in the east coast of Sumatra around 500-1000 ha [9]. Indonesian mangrove, however, has percentage mangrove loss was 1.7% [9], slightly similar to this study (1.06%). Mangrove conversion to aquaculture also has been reported in Kalimantan and Sulawesi [9].

Reforestation activity was observed in this study and occurred in ten regencies for 34,347.06 ha during observation, while the deforestation occurred 595,220.57 ha for 25 years (Table 2). Humbang Hasundutan was the only regency had negative reforestation where reforested 24,897.37 ha compared to deforestation 15,513.15 ha. The rehabilitation program is proposed by the involvement of the local communities dependent on the mangrove ecosystem for sustenance [10]. Protecting logged forests lead greater carbon emissions reductions (21%) than protecting intact forests alone (9%) and is vital for mitigating carbon dioxide emissions [8].

4. Conclusions

Major driver of North Sumatra deforestation, especially from the secondary and primary forest (dry land, mangrove, and peat land) was derived from plantation estate (oil palm plantation). The increasing loss of North Sumatra forest and increasing non-forest lands implies to conservation efforts and developing sustainable forest management.
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