Identification of land cover changes before and after forest and land fires in conservation areas of North Sumatra, Indonesia

A S Thoha*, N Sulistiyono, N Saraswita, D Wiranata, S M Sirait and R Inaldi
Faculty of Forestry, Universitas Sumatera Utara, Medan, North Sumatra 20155, Indonesia

*Email: a.siddik@usu.ac.id

Abstract. Damage to conservation areas in North Sumatra can be mitigated by understanding the pattern of land cover change, which can be performed by detecting hotspots and their temporal and spatial patterns. This study aimed to explore land cover spatially and temporally before and after forest fires in the conservation areas in North Sumatra. Data on the hotspots, satellite imagery, land cover maps, and field verification were used to see the transition of land cover changes before and after forest and land fires. Temporal and spatial analysis was employed to see the trend of land cover changes of the land before and after the fires. Field verification was conducted through observations and interviews related to land cover conditions in the field caused by forest and land fires. This study found three conservation areas with the highest number of hotspots in 2014 in the period 2001-2019, including Gunung Leuser National Park (GLNP), Dolok Surungan Wildlife Reserve, and Barumun Wildlife Reserve during the 2001-2019 period. In 2010 and 2014 there were strong indications of a large area of land burning in three conservation areas. The burned land was near the outer boundary of the conservation areas and continued to expand into the areas over time. The area of the non-forest cover was relatively stable between periods prior to the discovery of several hotspots. Changes in forest cover to non-forest have become more widespread after the highest number of hotspots were detected in 2010. Conservation area management and various parties need to prevent the expansion of forest clearing considering the strategic role especially in GNLP as a world heritage.

1. Introduction
Forest and land fires occur almost every year with large impacts and losses in various sectors. It occurs every year throughout Indonesia, produces large greenhouse gas emissions [1] and causes regional air quality problems [2,3]. The prevalence of forest and land fires in Indonesia is influenced by both climate [4,5] and land cover changes [6]. This issue requires a proper understanding of how the management of agricultural land and plantations can be improved to minimize fires and related environmental impacts [7,8].

Emissions from fires on peatlands in Indonesia contribute to climate change and worsen air quality problems [2,3]. Major fires across Indonesia in 2015 produced 700-800 million tons of CO2 [9,10], and affected 69 million people due to poor air quality [3]. Exposure to air pollution is expected to cause 11,880 deaths in the short term [3] with up to 100,300 premature deaths in the long run [11]. Peatland areas that experience fast land cover changes and frequent fires in central and southern Sumatra and southwest Kalimantan contribute the most to regional air quality problems [12].
Major fires in Indonesia occur mostly during dry years linked with the El Nino Southern Oscillation and Indian Ocean Dipole [4], with nonlinear fire sensitivity to dry conditions [13]. Undisturbed tropical forests and wet peatlands are frequently fire resistant [14,15]. Deforestation has enhanced the flammability of peat and given ample fuel [16]. This suggests that anthropogenic land cover changes have modified the prevalence of fires throughout the country.

Fires occur every year throughout a large area of Indonesia, even in years when there is no drought [17]. Satellite studies of fire detection [4,5,9] and burned areas [18] provide new information on fire occurrence and its relationship to climate change and land use. Over ten years, 16.2 million ha of land in Kalimantan, or 21% of the land surface was burned [19].

Land cover changes are related to fires as a result of a multi-year process that includes road construction, logging, and forest fragmentation [20,21]. Since fire and deforestation have direct interactions, understanding the relationship between them is critical [22]. Fires in Indonesia are caused by four main factors: fire is used as a tool in land clearing; fires can be accidental or intentional; fire is used as a weapon in land tenure or land use disputes, and fire is connected with resource extraction [23]. The same study identified five factors causing land fires, including ownership and land use allocation conflicts and competition, forest degradation practices, economic incentives/disincentives, population growth and migration, inadequate firefighting and management capacity.

Our analysis focuses on the dynamics of hotspots associated with various types of land cover before and after fires in conservation forest areas in North Sumatra province. This study is necessary due to the limited information related to forest damage caused by fires in conservation areas. This study aimed to spatially and temporally explore land cover before and after forest fires. It is expected that this study can provide updated information regarding the dynamics of land cover in conservation areas to assist forest management and control of forest and land fires.

2. Materials and Method

2.1. Study area
This study was conducted in North Sumatra focusing on Conservation Forest areas consisting of Wildlife Sanctuaries, Wildlife Reserves, Nature Parks, Forest Parks, Hunting Parks, and National Parks. According to the latest data of the determination of forest areas by the Decree of the Minister of Environment and Forestry No. 8088 of 2018 concerning Development Map of Forest Area Inauguration of North Sumatra Province, the area of Conservation Forest in North Sumatra is 424,476.01 ha or about 14% of the total forest area.
2.2. Data Analysis
Data collection and data processing were conducted in the Conservation Forest areas in North Sumatra and at the Conservation of Forest Resources Laboratory, Faculty of Forestry, Universitas Sumatera Utara. The data obtained and analyzed were secondary. The data was obtained from the Director General of Forestry Planning and Environmental Management of the Ministry of Environment and Forestry and downloaded from the Earth Explorer of the United States Geological Survey (USGS) site and NASA’s Active Fire Data site.

Data analysis performed includes temporal, spatial, and attribute data analysis from the hotspots. Analysis of temporal data aims to determine the distribution of hotspots over time so that the highest hotspot density is determined as the reference for the year of the occurrence of fire. Spatial data analysis includes image processing and identification of land cover/use. Attribute data analysis concerns the distribution of hotspots indicating strong forest fires based on the location of the conservation area, density, and distribution per land cover.

The hotspots used were those from 2001-2019. The hotspots were monitored from the data of remote sensing satellites and represent actual fire incidents occurring in the field. The higher the level of confidence, the more likely the hotspot will be a forest and land fire. Hotspots, which are strong indications of fire occurrences, have a level of confidence greater than 50% [24] and are included in the hotspot category for immediate response in forest and land fire control [25]. In this study, hotspots were reclassified using a GIS tool of ArcGIS version 10.8 to select only hotspots with a confidence level above 80. The hotspots employed in this study were those at all confidence levels for determining temporal and spatial patterns. To determine locations that have strong indications of forest and land fires and land cover dynamics, hotspots with confidence levels above 80 were used.

Land cover was identified using ArcGIS software version 10.3. Image classification technique using Landsat OLI 8 satellite was divided into two by visual classification. Identification of land cover in this study used visual classification guided by Technical Instructions for Interpreting Medium

Figure 1. Study area
Resolution Satellite Imagery for Data Updates of National Land Cover [26]. Visual classification is a classification technique by inferring the specific characteristics of objects in the image in terms of the color, shape, size, pattern, shadow, texture, and location of the object. Attribute data analysis was employed to make the analysis of land cover/use changes and their causal factors easier. Analysis of land cover changes was conducted by comparing land cover before and after fires. Land cover changes might be observed over the period.

Field verification and interviews at selected locations based on hotspot density were carried out to observe changes in land cover and use that occurred. Furthermore, they aimed to observe community farming patterns in North Sumatra to determine the factors causing forest fires that resulted in changes in land cover/use. The causal factor analysis was conducted to determine the impact of forest fires.

3. Results and Discussion

3.1. Spatial Distribution of Fire Hotspots in Conservation Areas in North Sumatra

Spatially, the hotspots indicating forest and land fires were scattered across 11 conservation areas in North Sumatra. The spatial analysis of the distribution of hotspots in 2001-2019 with the boundaries of Conservation Areas in North Sumatra shows the distribution of the number and density of hotspots for 19 years (Table 1). The annual distribution of hotspots in conservation areas in North Sumatra is shown in Table 1.

| Conservation Area Name                              | Number of Hotspots | Average Hotspots Per Year | Area (Ha)  | Density (Hotspot/Km²) |
|-----------------------------------------------------|--------------------|---------------------------|------------|-----------------------|
| Dolok Surungan Wildlife Reserve                     | 69                 | 4                         | 21486.43   | 0.32                  |
| Dolok Sipirok Wildlife Sanctuary                    | 1                  | 0                         | 7214.52    | 0.01                  |
| Nature Sanctuary of Sei Ledong                      | 34                 | 2                         | 741.75     | 4.58                  |
| Karang Gading and Langkat Timur Laut Wildlife Reserve| 6                  | 0                         | 13413.92   | 0.04                  |
| Barumun Wildlife Reserve                            | 130                | 7                         | 36260.89   | 0.36                  |
| Siranggas Wildlife Reserve                          | 5                  | 0                         | 5599.22    | 0.09                  |
| Bukit Barisan Forest Park*                           | 513                | 27                        | 39678.60   | 1.29                  |
| Batag Gadis National Park                            | 19                 | 1                         | 72261.25   | 0.03                  |
| Gunung Leuser National Park                          | 193                | 10                        | 244071.94  | 0.08                  |
| Holiday Resort Nature Park                           | 8                  | 0                         | 2079.34    | 0.38                  |
| Sijaba Hutaginjang Nature Park                       | 2                  | 0                         | 631.47984  | 0.32                  |

Notes: *located in the Disaster-Prone Area I of Mount Sinabung Eruption

Bukit Barisan Forest Park, Gunung Leuser National Park, and Barumun Wildlife Reserve had the highest number of hotspots detected in conservation areas in 19 years. As seen from the annual average of hotspots detected, three conservation areas had the highest average hotspots, including Gunung Lesuser National Park and Barumun Wildlife Reserve, and Dolok Surungan Wildlife Reserve. The Bukit Barisan Forest Park was eliminated from the selected location as the hotspots detected were in the prohibition zone of the Disaster-Prone Area I of the Mount Sinabung Eruption.

Based on the density of hotspots, the Nature Sanctuary of Sei Ledong had the highest value of 4.58 hotspots/Km². It indicates that the Nature Sanctuary of Sei Ledong has the potential for intensive forest fire activity in the future. The magnitude of the hotspot density value is due to the extremely small area of Nature Sanctuary of Sei Ledong, allowing a few hotspots to be observed very tight in the area.
The Nature Sanctuary of Sei Ledong Conservation Area is located in a peat area in North Sumatra. Based on the results of interviews and field surveys, this area used to be a forest area but has turned into an oil palm plantation currently. Peatlands are extremely susceptible to fire when converted. A study [1] stated that the peat area in North Labuhanbatu in Kualuh Leidong is one of the areas with a high number of hotspots. A study by Thoha et al. [27] also revealed that peatland areas in the conservation areas in Central Kalimantan also frequently experience fires after being cleared for plantations and agriculture.

Gunung Leuser National Park has consistent dissemination of hotspots in particular areas annually. Furthermore, the GLNP area is a conservation area with the designation of a World Heritage Site that has received international attention, so that minor disturbances to the area must receive attention for study. In 2008, the status of GLNP became increasingly critical as it was stipulated as National Strategic Area by the Indonesian government [28].

The Bukit Barisan Forest Park area is not a study area to be discussed further in the dynamics of land cover although it has the highest number and average of hotspots. The majority of the location of hotspots in the Bukit Barisan Forest Parks are located in an area of less than 3 km radius from the crater of Mount Sinabung, Karo Regency, North Sumatra. The prevalence of a large number of hotspots originated from the eruptive activity of Mount Senabung that occurred from 2010 to 2019. For this reason, the hotspots included in the Bukit Barisan Forest Park area were not subjected to further investigation and field surveys.

Based on a descriptive analysis of the annual distribution of hotspots in conservation areas in North Sumatra, it was found that the hotspots were detected almost every year in particular conservation areas (Figure 2). Temporarily, not all conservation areas have detected hotspots throughout the past 19 years from 2001-2019. In fact, the conservation area of Dolok Sipirok Wildlife Sanctuary has only one hotspot detected for 19 years. On the other hand, hotspots in Barumun Wildlife Reserve and Gunung Leuser National Park (GNLP) were detected every year from 2001-2019. This study also found that there is a conservation area that has detected a number of hot spots in the last five years, namely Dolok Surungan Wildlife Reserve.

Scoring for rainfall was based on the average value of the annual rainfall. The relatively large average rainfall could result in higher landslide-prone levels. Rainfall in the Dairi District was about 2517 mm/year and had a score of 4 on the climate parameter (Table 5 and Figure 5). The rainfall data obtained from the BPS of Dairi District was only one data, this was due to the limited information on rainfall data provided by the Dairi District Government.
The majority of the incidents of fires in conservation areas in North Sumatra occur on mineral lands because the area of peatlands in North Sumatra is not too large. Similarly, a study [3] found that the conservation areas experiencing fires were quite large on mineral lands.

Generally, land fires in conservation areas occur on land experiencing clearing due to human activities. The burned land is no longer a type of forest land cover, but shrubs, reeds, and agricultural land. In the GLNP area, for instance, the hotspots occur on lands that have been cultivated by the community as indicated by the results of surveys and interviews. A study [29] in North Sumatra revealed that unmaintained land in the form of shrubs and reeds became extremely susceptible to fire. A study [25, 31] also found that changes in forest cover to oil palm plantations made hotspots more frequently detected in these areas. A study [30] also disclose that the previously burned lands were abandoned land in the form of shrubs which became plantation areas later.

3.2. Trajectory of Land Cover Changes in Conservation Areas Detected by Hotspots

3.2.1. The trajectory of land cover changes of burned land in the GLNP. Analysis of land cover changes through satellite imagery indicates the dynamics of land cover changes in areas detected as land cover in three conservation areas in North Sumatra, including GLNP, Barumun Wildlife Reserve, and Dolok Surungan Wildlife Reserve. The results of the analysis of land cover changes from the three areas can be seen in Figure 2, Figure 3, and Figure 4 respectively.

Figure 3 shows land cover changes before and after 2010 in the GLNP area. In 2010, the highest number of hotspots in the GNLP area in the Besitang Langkat area and its surroundings were detected in the 2001 – 2019 period. The presence of hotspots indicates land clearing by burning in order to clear forest land and convert it to other uses such as agricultural land, plantations, and owned or claimed lands.
There were land cover changes from 2001, 2005, 2010, 2015, and 2020 (Figure 2). Before 2010, there was a reduction in primary dryland forest cover based on color and hue shown by satellite imagery (dark green with a rough hue) to secondary dryland forest (green with a rough hue), shrubs and open ground (yellow and red). In 2001, primary dry land forest cover started to decrease caused by land clearing into open land and dry land agricultural land. The non-forest cover is increasingly broader until it continues to expand into the area of forest cover in 2005.

![Figure 3](image)

**Figure 3.** The trajectory of land cover changes of burned land in the GLNP area (red line indicates conservation area boundaries): Landsat 8 images show natural color in GLNP in (a) 2001, (b) 2005, (c) 2010 overlay with hotspots (white circle), (d) 2015, (e) 2019, and (f) 2020

After 2010, there was an expansion of conversion from forest to non-forest in the GLNP area. In 2015, according to image analysis (Figure 2d), the area that was turned into non-forest was increasingly expanded into the GLNP area. In the following year of 2019-2020, the area of non-forest land within the GLNP area did not expand significantly (Figure 2e and Figure 2f).

According to the results of interviews with communities around the GLNP area, land cover changes have occurred because of forest encroachment since the 1990s. The results of the study conducted by [32] show that the encroachment in the Besitang GLNP area started after the entry of Acehnese refugees caused by armed conflict. The Acehnese refugees who had no place to live then encroached on the forest by opening a new area of residence. Following that time, the Acehnese refugee settlements were spread out in several refugee blocks covering some villages including Sekoci, Sei Minyak, Barak Induk, and Damar Hitam.

A study by [33] also mentioned forest cover changes from forest to dry land agricultural land which is quite extensive in the Besitang watershed, whose area is also included in the GLNP area. Another study [8] found that the area of encroachment in GLNP in 2011-2013 in Sekoci Village alone reached 6,800 Ha. Encroachment was also found in other villages including Cinta Raja, Sei Lepan and Lau Sekelam Villages.
3.2.2. The trajectory of land cover changes of burned land in the Dolok Surungan Wildlife Reserve. Land cover changes before and after 2015 in the Dolok Surungan Wildlife Reserve area are shown in Figure 4. The highest number of hotspots were detected in 2015 (Figure 3d) in the Dolok Surungan Wildlife Reserve area in the Kuala Beringin North Labuhanbatu, Hutarim Baru, and Meranti Pohan areas, Toba Samosir Regency and surrounding areas in the period 2001 – 2019. The presence of hotspots indicates land clearing by burning to clear forest land for diverse uses of land including agricultural, plantation, and tenure.

![Figure 4](image.png)

**Figure 4.** The trajectory of land cover changes burned in Dolok Surungan: Landsat 8 images show natural color in Dolok Surungan (red line indicates boundaries) in (a) 2001, (b) 2005, (c) 2010 (d) 2015 overlay with hotspots (white circle), (e) 2019, and (f) 2020

The results of the identification of satellite images in the Dolok Surungan area indicate that only a few changes occurred. From 2001 to 2010, the land cover was relatively stable in the conservation area which was dominated by Primary and Secondary Dryland Forest. After 2015, the highest number of hotspots were detected for 19 years, showing a slight change in another land cover of the presence of shrubs, mixed bushland agricultural land in the area and open land. It may be identified in the image as shown by the appearance of light green areas, light green with rough hues, and pink with subtle hues [26]. The results of the field survey found areas of fire marks on the boundary of the Dolok Surungan Wildlife Reserve area and some of them were expanded into the wildlife reserve area.

3.2.3. The trajectory of land cover changes of burned land in Barumun Wildlife Reserve area. Land cover changes in the Barumun Wildlife Reserve area before and after 2015 are shown in Figure 5. The highest number of hotspots were detected in 2015 (Figure 3d) in the Barumun SM area in the Hutarim Baru Sayur Matus area in Barumun District and Pagaran Bira Julu Village, Sosopan District, Padang Lawas Regency, in the period 2001 – 2019. The presence of clustered hotspots indicates land clearing by burning to clear forest land for diverse uses of land such as agricultural, plantation, and tenure.
Based on the results of the identification of satellite images in the Barumun Wildlife Reserve area, it can be seen that not many changes have occurred (Figure 4). From 2001 to 2010, land cover in the conservation area was relatively stable with primary dry land forest land cover, secondary dry land forest, and dry land agricultural land. After 2015, the highest number of hotspots were detected for 19 years, followed by another land cover of shrubs and mixed agricultural land. This can be identified in the images as shown by the appearance of light green and light green areas with a rough hue [26]. Areas experiencing changes in land cover start from the outer boundary of the area and then extend into the area. According to the results of field observations and field surveys, land burning is carried out to clear rubber plantations and dry land agricultural land after forest degraded. The study in Riau by [34] also found the same pattern which fires occurrences tend to increase after forest is degraded. According to study about fire activities in Central Kalimantan by [35] also found that after forest is degraded, community generally begin drying biomass and the burn it. Burning land for land preparation still use by community because the method is cheaper, easier and faster than other way. This practical should not occur in conservation area because the area very fragile to change. Furthermore, the conservation area is the last protected place for mega-biodiversity and protect for various disaster in North Sumatera Province. This study provide suggestion to improve the management practice in order to minimize the illegal activities that can change forest cover in conservation area in North Sumatera Province.

4. Conclusion
This study fund a temporal pattern of hotspots over year in conservation areas in North Sumatra. Three conservation areas have the highest number of hotspots, including Gunung Leuser National Park, Dolok Surungan Wildlife Reserve, and Barumun Wildlife Reserve. This study also revealed that the highest number of hotspots were detected in 2014 during the period 2001-2019. In 2010 and 2014, there were indications of extensive land burning as shown by the results of the identification of burnt land on satellite images in the three conservation areas. The burnt land is close to the outer boundary of the conservation area and continues to expand into the area in the following period. Before many
After the highest number of hotspots were detected in 2010, there was an increase in non-forest areas, presumably due to increased access to enter the area after the opening of the forest caused by the fire. Conservation area management and various parties need to prevent the expansion of forest clearing considering the strategic role of as a world heritage.

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