

BEST MANAGEMENT PRACTICE SHOULD PRIORITIZE THE INDEPENDENT FARMERS TO STOP HAZE

PRAKTEK MANAJEMEN TERBAIK HARUS MEMPRIORITASKAN PETANI INDEPENDEN UNTUK MENGHENTIKAN KABUT ASAP

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ABSTRACT

The severe haze disaster in Southeast Asia requires quantification of the drivers of fire in Sumatra. Without a holistic method, the conclusions are inaccurate. This study used remote sensing data and Maxent modeling technique to model and predicted the distribution of fires in Riau, Sumatra. The MODIS hotspot data from 2001 to 2014 in the study area were gathered. The hotspot data were examined for the human-ignition factors such as deforestation, land management, land system, slope, and forest area status to understand the driver of fire. The results showed that the fire is human-caused. There were three main findings. First, the study area experienced rapid deforestation, with 1.7 million ha of forests was lost from 1990 to 2013. Second, the fire risk associated with unsustainable plantation development and unclear land tenure. The yearly hotspots were high soon after deforestation and reduced gradually. Most of the hotspot from 2001 to 2014 occurred in an area that developed for oil palm by the independent farmer (73.7%). In contrast, the area developed by the company (acacia, rubber, and oil palm) has fewer hotspots. Nevertheless, natural forests were shown to be fire-resistant. Third, the land system was the most important driver of fire, followed by landholders and deforestation. On the contrary, slope and forest area status showed the marginal driver of fire. These results indicated the importance of peat swamp forest, sustainable plantation management, and land tenure to mitigate haze disaster. Fire distribution modeling can develop fire risk maps that can help the government focus on high-risk areas.

Keywords: *Deforestation, landholder, industrial forest plantation, hotspot, Maxent model, sustainability.*

ABSTRAK

Bencana kabut asap yang parah di Asia Tenggara membutuhkan kuantifikasi penyebab kebakaran di Sumatra. Tanpa metode holistik, kesimpulan menjadi tidak akurat. Penelitian ini menggunakan data penginderaan jauh dan teknik pemodelan Maxent untuk memodelkan dan memprediksi distribusi kebakaran di Riau, Sumatra. Data hotspot MODIS dari tahun 2001 hingga 2014 di wilayah studi dikumpulkan. Data hotspot diperiksa untuk mengetahui faktor pencetus api dari manusia seperti deforestasi, pengelolaan lahan, sistem lahan, kemiringan, dan status kawasan hutan untuk memahami penyebab kebakaran. Hasil penelitian menunjukkan bahwa api disebabkan oleh manusia. Ada tiga temuan utama. Pertama, wilayah studi mengalami deforestasi yang cepat dengan 1,7 juta ha hutan hilang dari tahun 1990 hingga 2013. Kedua, risiko kebakaran terkait dengan pengembangan perkebunan yang tidak berkelanjutan dan kepemilikan lahan yang tidak jelas. Titik panas tahunan tinggi segera setelah deforestasi dan berkurang secara bertahap. Sebagian besar hotspot dari tahun 2001 hingga 2014 terjadi di daerah yang dikembangkan untuk kelapa sawit oleh petani mandiri (73,7%). Sebaliknya, area yang dikembangkan oleh perusahaan (akasia, karet, dan kelapa sawit) memiliki lebih sedikit titik api. Namun demikian, hutan alam terbukti tahan api. Ketiga, sistem lahan adalah pendorong kebakaran paling penting diikuti oleh kepemilikan lahan dan deforestasi. Sebaliknya, kelerengan dan status kawasan hutan sedikit memicu kebakaran. Hasil-hasil ini menunjukkan pentingnya hutan rawa gambut, pengelolaan perkebunan berkelanjutan, dan kepemilikan lahan untuk mengurangi bencana kabut asap. Pemodelan distribusi kebakaran dapat mengembangkan peta risiko kebakaran yang dapat membantu pemerintah fokus pada area berisiko tinggi.

Kata kunci: *Deforestasi, pemilik lahan, hutan tanaman industri, hotspot, model Maxent, keberlanjutan.*

I. INTRODUCTION

The causes of fires in Indonesia are quite complex [1]. Fires occur due to a combination of predisposing conditions and human ignition factors. Some of the predisposing conditions are low rainfall, deforestation, type of land cover, land management, and peatland degradation. Human-induced fires can be intentional or unintentional fires. Some of the careless activities which cause fires include the poor disposal of cigarettes, uncontrolled campfires, and other out of control fire activities.

Among tropical countries, Indonesia has the highest prevalence of deforestation [2]. Some of the negative impacts include an increase in temperatures and reduction of soil moisture and rainfall. This enhances drought conditions and affects the regional climate [3]. Moreover, peatland deforestation results in unstable water level conditions. This causes floods during the rainy season and fires during the dry season [4]. Further, subsidence, carbon emissions, and peat oxidation [5] also occur. For example, Sumatra experienced rapid deforestation with a forest loss of around 3.4 million ha (24% of the deforested area) from 2000 to 2010 [6].

The type of land cover (e.g. plantation or forests) also affects fire intensity. Fires occurred most of the time in Riau's deforested areas when compared to natural forests or industrial plantations [7]. The fire sources have changed from peat swamp forests to deforested areas because of peatland drainage in the Mega Rice Project [8]. Furthermore, fire also disturbed ecological succession in Riau, which results in creating large shrublands in post-fire sites [9].

The cause of fire ignition is generally associated with land mismanagement, which is partially regulated by land tenure [10]. Small landholders are more secured against fire than those who are large landholders. This is because small landholders' area is

usually more intensively managed than large landholders area [11]. Small landholder plantations mostly consist of mixed forest plantation, and may also include rubber, coconut, sago palm, and paddy fields. Large landholders' plantations consist of monoculture crops of oil palm, acacia, and sago palm [12]. Small landholders and large landholders are responsible for fires in Riau [13]. Furthermore, accessibility to peatland increased fire occurrences [14].

The utilization of fire to clear the land should be minimized, particularly during the drought period. This requires an understanding of a fire's location, predisposed conditions, and possible causes. Although it is essential to highlight the main trends on a regional scale, generalization will lead to inconsistent, uncertain, and confusing results. This refers to the fire regime, which is specific in various regions. For example, Northern Sumatra was more sensitive to short-lived fires when compared to Southern Sumatra and Southern Kalimantan [15]. In Riau, major fire events are no longer restricted to drought years, which is different from other areas in Indonesia [7].

This study aimed to determine where and why fires occur in Riau, Sumatra. This includes examining the land management and deforestation processes that affect the intensity and sizes of fires. Riau has the largest peatland area making it one of the most fire-prone provinces in Indonesia. Due to its location, Riau contributes significantly to haze pollution in Malaysia and Singapore. As a result, this study focuses on two key questions: (1) Is deforestation connecting to fire? (2) Are land cover and land management types affecting fire activity?.

II. METHODS

1. Study area

We use a single LANDSAT scene (Path/Row: 127/059) as the study area is located in the northern part of Riau province.

Riau is located in the center of Sumatra (2°35'N–0°58'S, 100°13'E–103°50'E). It covers an 8.9 million ha area with a total population of 5.5 million, and population density was 62 people per km² in 2010 [16]. This province has diverse farmers (new and old settlers), land cover, and land management practices.

2. Mapping deforestation, landholder, and hotspot

A deforestation map produced by Centre for International Forestry Research (CIFOR) was used [7]. The deforestation map was made with supervised and visual classification of LANDSAT images. The deforestation map categorized into deforestation before 1990, deforestation from 1990 to 2000, and yearly deforestation from 2000 to 2013 (Table 1).

A landholder map from CIFOR was used [7]. This map was generated from LANDSAT and concession map. The landholder was differentiated into areas developed by plantation companies, areas occupied by small-scale agriculturalists, and idle undeveloped lands.

Hotspot data (2001 to 2014) were downloaded from the National Aeronautics

and Space Administration via the Fire Information for Resource Management System (FIRMS) data portal. MODIS fire hotspot data show the coordinates of the center of 1 km² pixel [17] where the persistent fire was detected from a MODIS image using an algorithm [18].

3. Assessing the drivers of fire with Maxent model

The Drivers of fire were computed in Maxent 3.4.1, a free software (https://biodiversityinformatics.amnh.org/open_source/maxent/). Maxent requires data points in format of comma-separated values (CSV) with three columns: code, longitude, and latitude. The data points (hotspot) were converted to WGS 1984 projection. X, Y coordinates in the attribute tables were updated with the Calculate Geometry tool. The updated attribute tables (DBF format) were converted CSV format with Microsoft Excel for use in Maxent software.

Maxent need all environmental variables in ASCII raster format with the same projection system, geographic reference, geographic extent, and grid cell size. First, environmental variables in shapefile format

Table 1. Data collection, description, and source.

Data	Description	Source
Deforestation	1990 to 2013	https://data.cifor.org/dataset.xhtml?persistentId=doi:10.17528/CIFOR/DATA.00079
Land ownership	2013	https://data.cifor.org/dataset.xhtml?persistentId=doi:10.17528/CIFOR/DATA.00081
Repprot	1990	https://databasin.org/datasets/eb74fe29b6fb49d0a6831498b0121c99
Slope	1990	Geospatial information agency
MODIS hotspot	2001 to 2014	https://firms.modaps.eosdis.nasa.gov/download/
High-resolution image	2013 to 2014	Digital Globe via Google Earth
Administrative	Riau Province	– Geospatial Information Agency of Indonesia – Planning Agency of Riau
Forest boundary	Riau Province	Ministry of Environment and Forestry
Concession boundary	Riau Province	Ministry of Environment and Forestry
Peatland map	Riau Province	Wetlands International
Ground truth	2005 to 2014	Field survey

were clipped to the extent of land ownership map using Geoprocessing tool in ArcMap 10.2. This clipped process set the geographic reference, projection system, and geographic extent for each environmental variable that was set precisely the same. Second, with the conversion tool, the clipped files were converted to raster with processing extent, and raster analysis used land ownership raster file. All environmental variables used WGS 1984 projection and 1 km² grid cell size. Third, using DIVA-GIS 7.5.0, the modified environmental variables were converted to ASCII files and stored in a folder. Fourth, run Maxent model, the directory of ASCII file was uploaded into the “Environmental Layers” and hotspot data (CSV) was uploaded into the “Sample”. We used a categorical parameter in environmental layers, logistic output format, respond curves, and jackknife to measure variable importance.

Maxent output maps (ASCII) were converted to a floating-point raster grid using the conversion tool. Logistic outputs

from Maxent software indicated 1 is the best condition for fire occurrence, and 0 is inappropriate conditions.

III. RESULT AND DISCUSSION

1. Relationship between deforestation, landholder, and fire

Riau experienced rapid deforestation from 1990 to 2013 (Table 2). Over the past 23 years, forest area declined rapidly from 2,080,000 ha in 1990 to 360,263 ha in 2013. More than four-fifth (1.7 million ha) of forests were lost from 1990 to 2013. The highest deforestation occurred in the last five years from 2008 to 2013 (0.5 million ha).

Human uses fire to clear deforested land and forest. One-third of Riau's hotspots from 2001 to 2014 (32.9%) were located in deforested land in 2000 (Table 2). Deforested land from 1990 to 2000 showed high hotspots after deforestation (62.5% in 2001) and reduced gradually to 14% in 2014, shown in Figure 1. Most of the hotspot from

Table 2. Period of deforestation and hotspots number.

Period of deforestation	Hotspots number	% Hotspot	Area (ha)	% area	Hotspot density (Km ²)
1990-2000	21,905	23.0	868,228	27.1	2.5
2000-2001	810	0.8	13,794	0.4	5.9
2001-2002	3,021	3.2	23,017	0.7	13.1
2002-2003	2,417	2.5	18,168	0.6	13.3
2003-2004	6,199	6.5	58,282	1.8	10.6
2004-2005	8,389	8.8	81,872	2.6	10.2
2005-2006	6,213	6.5	72,509	2.3	8.6
2006-2007	2,064	2.2	38,910	1.2	5.3
2007-2008	3,031	3.2	41,905	1.3	7.2
2008-2009	7,439	7.8	86,832	2.7	8.6
2009-2010	4,794	5.0	82,573	2.6	5.8
2010-2011	3,323	3.5	50,166	1.6	6.6
2011-2012	6,522	6.8	90,726	2.8	7.2
2012-2013	6,453	6.8	192,755	6.0	3.3
Forest 2013	3,313	3.5	360,263	11.3	0.9
Non-forest in 1990	9,478	9.9	1,122,219	35.0	0.8
Total	95,371		3,202,219		

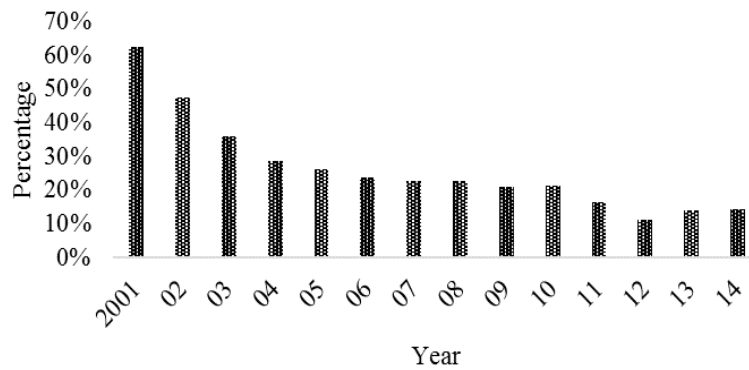


Figure 1. The trend of the hotspot in the area that deforested in 1990 to 2000 period. Fire occurrence will reduce after plantation developed.

Table 3. Type of landholders in 2013 and hotspots number (2001 to 2014).

Type of landholders	Hotspot numbers	% Hotspot	Area (ha)	% area	Density (Km ²)
Developed by communities for oil palm	70,329	73.7	1,771,322	55.3	4.0
Developed by communities for rubber	121	0.1	20,181	0.6	0.6
Developed by company for acacia	9,380	9.8	276,746	8.6	3.4
Developed by company for oil palm	12,033	12.6	769,371	24.0	1.6
Developed by company for rubber	22	0.0	4,336	0.1	0.5
Forest	3,486	3.7	360,263	11.3	1.0
Total	95,371		3,202,219		

2001 to 2014 occurred in the area developed for oil palm by independent farmer (73.7 %) (Table 3). On the contrary, the area developed by the company (acacia, rubber, and oil palm) has fewer hotspots. However, the forest has the least hotspot density (1 km²) of all types. The condition of hotspot occurrence is almost similar every year from 2001 to 2014. Fire is not directly connected with deforestation, and fire was used to clear deforested land.

The previous study suggest that fire has been strongly associated with peatland deforestation . Instead, there are two types of deforestation in Sumatra: (1) Unmanaged land that leads to persistent fire and (2) managed land for industrial plantation [19]. Our study gives a new perspective that fire target unmanaged land with unclear land tenure. Most of the fires are connected with

human activities because natural ignitions are very limited. Thus, fuel condition such as soil moisture is an essential factor to reduce the fire. In addition, humans affect fuel condition (amounts, composition, and configuration) through land use and land management [20]. Therefore, effective fire management should targeted independent farmers group in unmanaged land. Independent farmers use fire to develop plantation.

2. The driver of fire

The land type was the most important driver of fire with permutation importance was 23 is presented in Table 4. This is because most of the hotspot located in peat swamp (77,7%) with hotspot density was 5,9 shown in Table 5. The second highest hotspot density was hilly (2.4) followed by the alluvial valley (1,6). Peat swamp was

Table 4. Analysis of variable contributions.

Variable	% of contribution	Permutation importance
District boundary	34	19.3
Type of lands	25.2	23
Slope	15.2	6.5
Landholder	11.4	22.1
Period of deforestation	10.8	21.3
Status of forest area	3.5	7.9

Table 5. Type of lands and hotspots number.

Type of lands	Hotspot numbers	% Hotspot	Area (ha)	% area	Density (Km ²)
Plain	9,876	10.4	1,087,737	34.5	0.9
Aluvial plain	2,109	2.2	177,562	5.6	1.2
Meander	1,045	1.1	91,602	2.9	1.1
Aluvial valey	363	0.4	23,365	0.7	1.6
Mountains	49	0.1	35,729	1.1	0.1
Hilly	1,021	1.1	41,839	1.3	2.4
Tidal swamp	157	0.2	51,284	1.6	0.3
Peat swamp	74,086	77.7	1,259,729	40.0	5.9
Terrace	6,665	7.0	433,373	13.7	1.5
Total	95,371		3,202,219		

the most significant land system type in our study area (39.2%) followed by plain and terrace. Peat swamp has the highest hotspot every year from 2001 to 2014.

Landholders and deforestation were the next important driver of fire that contribute by independent farmers and time of deforestation (Table 4). The district boundary was also an important factor. This is because hotspots concentrated in the top eight hotspot highest district (52%). On the contrary, slope and forest area status showed the marginal driver of fire. Most of the hotspots occurred in the slope class 0% to 8% (98.8%) with hotspot density was 3.3. Based on forest area status, the production forest was the highest hotspot density, while conservation forest was the least hotspot density (Figure 2).

Recently, fires occurred mostly in unmanaged peatlands. This is because the

small land size in the unmanaged area is highly vulnerable to fire escape from surrounding properties (Cattau et al., 2016a). Fire management should prioritize unmanaged peatland and control the fire usage by all land operators during dry periods. We suggest the protection of remaining peatland swamp forest and peatland restoration to mitigate haze disaster. We predict the future severe haze disaster unless strong law enforcement is taken in peatlands showing in Figure 3.

3. Policy prevention

Forest and land fires have significant impacts on the environment and human life. Negative impacts include: (1) carbon gas emissions into the atmosphere thereby increasing global warming; (2) loss of habitat for wildlife resulting in ecosystem imbalances; (3) loss of trees which are oxygen-producing and absorbing rainwater

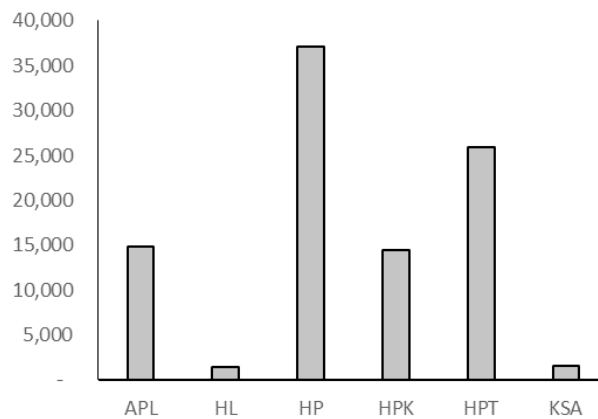


Figure 2. Number of hotspots based on forest area status.

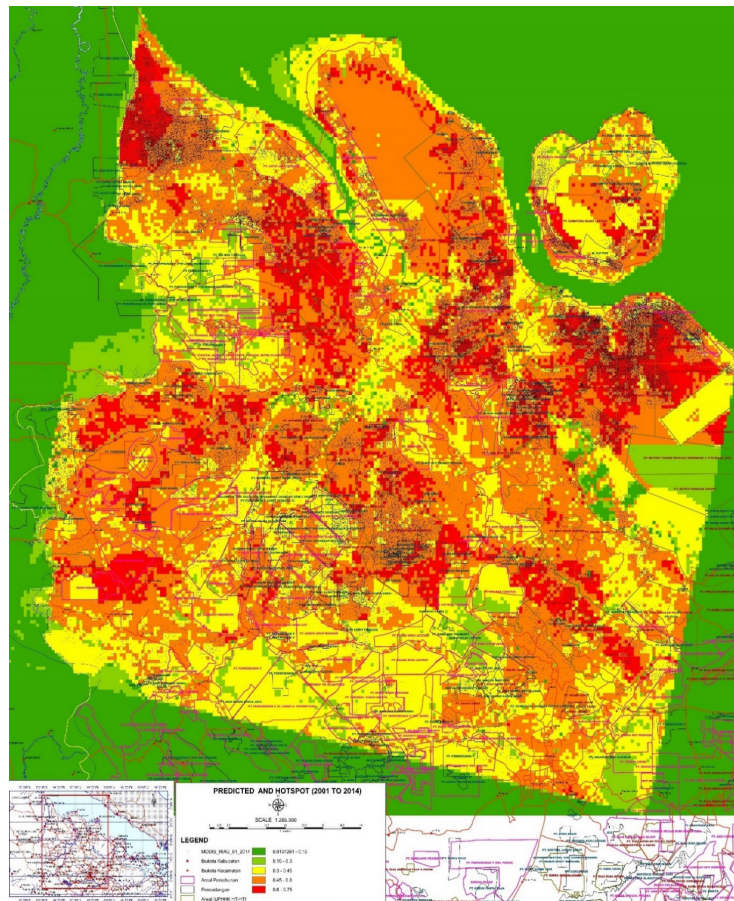


Figure 3. Long-term fire probability map hotspot between 2001 and 2014.

resulting in floods, landslides and droughts; (4) loss of industrial raw materials that will affect the economy; (5) reduced forest area that will affect the microclimate (weather tends to be hot); (6) air pollution which

disrupts people's activities and causes various respiratory diseases; and (7) decrease the number of tourists [21].

We proposed a set of recommendations for fires handling, based on the above-

mentioned key findings. First, the Government should develop an effective and permanent moratorium policy on peat swamp conversion and the ban on new oil palm licenses. The existing condition shows us that legal action against those suspected of starting fires is limited. Independent farmers still struggle to find economically feasible alternatives to fire.

Second, the Government should focus on best land management practices. Intact forests and peatlands must be conserved and supported by feasible alternative livelihoods. Another problem is land tenure, which impedes the government's enforcement efforts.

Third, legal access for communities living in forest areas under the social forestry scheme. Up to now, Peatland restoration simply means slowing down water in the canal with a lack of ownership and sustainability. These schemes can balance conservation and the economy. The farmers produce non-timber products such as coffee and honey while rewetting the peatland.

IV. CONCLUSION

Our results highlight the important effects of land management policies and rapid deforestation, on fire activities in Indonesia. Human ignites the fire in drought condition. The frequency and area of fires in this area are increasing due to continuing deforestation and unmanaged land. Our finding has important implications for peatland management and fire suppression efforts. Landscape management involving all stakeholders must be required to achieve effective fire management.

The effective management of existing natural forests, logging concessions, and unprotected forested peatlands could reduce fire risk. Besides, peatland restoration maybe is an effective way to prioritize fire suppression on the fire-prone area in a dry period. Future studies should focus on

adaptive crops under wet conditions, land clearing without fire, land tenure, community engagement, and alternative livelihoods for community members.

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