Research Article **Open Acces**

Hotspot Distribution Assessment on The Peat Hydrological Unit (PHU) in Riau Province

Hanum Resti Saputri[1,2], Rahmat Asy'ari[1,3], Abd. Malik A. Madinu[1,4], Ali Dzulfigar[1,2], Khairani Putri Marfi[1,2], Fajar Raihan[1,2], Muhammad Hisyam Fadhil[3,5], Salsa Fauziyyah Adni[1,2], Intan Nur Rahmadhanti[1,2], Eka Sartika Nugraha[1,4], Erianto Indra Putra[6], Istomo Istomo[6], Neviaty P Zamani[7], Rahmat Pramulya[8,9], Yudi Setiawan[10]

[1] *IPB Sustainable Science Research Student Association (IPB SSRS Association), IPB University, Bogor Regency 16680, Indonesia*
[2] *Undergraduate Student, Department of Silviculture, Faculty of Forestry and Environment, IPB University, Bogor Regency 16680, Indonesia*
[3] *SSRS EartInformatics Labs, SSRS Institute – SSRS Group, Bogor Regency 16680, Indonesia*
[4] *Undergraduate Student, Department of Geophysics and Meteorology, Faculty of Mathematics and Natural Sciences, IPB University, Bogor Regency 16680, Indonesia*
[5] *Undergraduate Student, Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor Regency 16680, Indonesia*
[6] *Department of Silviculture, Faculty of Forestry and Environment, IPB University, Bogor Regency 16680, Indonesia*
[7] *Center for Transdisciplinary and Sustainability Science (CTSS), IPB University, Bogor Regency 16680, Indonesia*
[8] *Research Center for Low Carbon Development, University of Teuku Umar, Aceh, Indonesia*
[9] *SSRS Gayo Leuser Highland Ecosystem Research Facility, SSRS Institute – SSRS Group, Bogor Regency 16680, Indonesia*
[10] *Center for Environmental Research (PPLH), IPB University, Bogor Regency 16680, Indonesia*

* Correspondence: hanumrestisaputri@gmail.com

Abstract: Indonesia is the third country with the largest tropical forest area in the world after Brazil and Congo. However, as time goes by the area of forest in Indonesia is decreasing. One of the dominant causes of forest destruction in Indonesia is forest fires. The type of forest that is frequently and susceptible to forest fires is forest on peatlands. Monitoring the distribution of hotspots is an important strategy in preventing forest fires on peatlands. Therefore, this research was carried out to design a platform for monitoring forest and land fires in forests on peatlands using a case study location in Riau Province. This monitoring platform utilizes remote sensing technology which uses NASA FIRMS MODIS hotspot data, BMKG rainfall data, and Sentinel-2 hydrology data. During the period 2005-2023, the most hotspots were found in 2005-2015, while the fewest hotspots were found in 2016-2023. The accumulated hotspot data is found in peat soil (PHU) as many as 138,523 hotspot (77.8%), while in mineral soil (non PHU) there are 39,583 points (22.2%). Riau Province, especially Rokan Hilir, Bengkalis and Pelalawan Regencies, are districts that require special attention in efforts to prevent forest and peatland fires because they have been detected to have the largest distribution of hotspots.

Keyword: Monitoring, peatland ecosystem, tropical forest fire

INTRODUCTION

Indonesia is one of the third countries with the largest tropical forest area in the world after Brazil and Congo (Arrafi *et al.* 2022). According to data from the Ministry of Environment and Forestry (KLHK) in 2019, Indonesia's forest area was 94.1 million ha or 50.1% of Indonesia's total land area (Pandia *et al.* 2019). However, as time goes by the area of forest in Indonesia is decreasing. The causes of land damage are dominated by illegal logging activities, land conversion for plantations, and forest fires (Wahyuni & Suranto 2021). The increase in population and the increasing number of investors who invest their capital to enrich themselves has caused all human activities to rely on land use, making land an increasingly scarce resource (Nakita & Najicha 2022).

Forest fires are one of the contributors to carbon emissions from the forestry sector which are caused by two main factors, namely natural and human factors (Rasyid 2014). The fires that occur are related to massive changes in land use every year. Based on Government Regulation Number 4 of 2001 concerning Control of Environmental Damage and/or Pollution, it is stated that forest and land fires are one of the causes of environmental damage and pollution (Anhar *et al.* 2022). Forest fires cause many detrimental impacts both from an ecological, social and economic perspective (Murtinah *et al.* 2017). Based on ecological aspects, forest and land fires can cause loss of existing biodiversity. Meanwhile, from an economic aspect, forest fires are very detrimental financially because forest and plantation products can decrease drastically. This financial impact is also related to social aspects of society which will impact poverty and public health problems.

Forest fires in Indonesia often occur in peat areas. Peatlands in Indonesia have an area of around 13.43 million ha spread over three large islands, namely Sumatra, Kalimantan, and Papua. The existence of this peat is starting to be threatened by unsustainable land use activities. Land use on peatlands is considered to have the potential to produce CO_2 emissions that burden the atmosphere. Peat is a wetland that is quite vulnerable (fragile) to environmental conditions. Peatland clearing requires good knowledge of peat characteristics in terms of fertility (thickness) and wetland ecosystem function (biodiversity and hydrology) (Soewandita 2018). Peatland is an area whose main composition consists of organic material deposits that have accumulated on the earth's surface over a long period of time due to incomplete decomposition under water-saturated conditions (Xu *et al.* 2018). Peatlands consisting of rotting and degraded organic material will produce large amounts of Greenhouse Gas (GHG) emissions, especially if the peatlands are burned (Saharjo and Novita 2022).

A monitoring system for forest and land fires must be implemented so that spatial assessments of fires, emission release processes, biodiversity, hydrological conditions (water level), and post-fire succession can be monitored and controlled optimally. Remote sensing plays an important role in monitoring forest and peatland fires. Utilization of remote sensing technology to detect hotspots is carried out by downloading data via the Fire Information for Resource Management System (FIRMS) Moderate Resolution Imaging Spectroradiometer (MODIS) satellite with Aqua and Terra sensors belonging to the National Aeronautics and Space Administration (NASA). Monitoring via remote sensing can provide essential information to support efficient, transparent decision making, and can be a reference in the management and governance of protected areas (Wang *et al.* 2020). Therefore, assessing this hotspot is important as an effort to protect peat ecosystems against climate change and preserve biodiversity.

METODOLOGI

Study Area

Administratively, the study location is located in Riau Province. This location consists of 10 districts and 2 cities, which consist of 166 sub-districts and 1,847 sub-districts/villages. Riau Province is geographically, geoeconomically and geopolitically located on a very strategic route. The Riau region stretches on the slopes of Bukit Barisan to the Strait of Malacca with an area of ± 8,999,896.34 Ha, where most of the land resources are peatlands with an area of 4,971,226.71 Ha (55.24%) and the remaining 4,028,669 Ha. 63 Ha (44.76%) is non-peat land (Taryono 2021). Astronomically, the Riau region is in a position between $01^{\circ}05'00''$ South Latitude to $02^{\circ}25'00''$ North Latitude or between $100^{\circ}00'00''$ East Longitude and $105^{\circ}05'00''$ East Longitude.

Data Source and Research Flow

The data used in this research is hotspot data taken via the Fire Information for Resource Management System (FIRMS) Moderate Resolution Imaging Spectroradiometer (MODIS) satellite with Aqua and Terra sensors belonging to the National Aeronautics and Space Administration (NASA), a map of the Indonesian Earth (RBI), indicative map of the Peat Hydrological Unit (PHU) taken via the Information System for Protection and Management of Peat Ecosystems (SiPPEG) website of the Ministry of Environment and Forestry (KLHK), rainfall data taken through the Meteorology, Climatology and Geophysics Agency (BMKG), and hydrological data via sentinel-2. According to Pratamasari *et al.* (2020), MODIS imagery is the most suitable image for identifying forest fires because of its daily temporal resolution. Hotspots were taken from 2005 to 2023, then the FIRMS hotspot data was downloaded in vector form in shapefile (shp) format. Then the

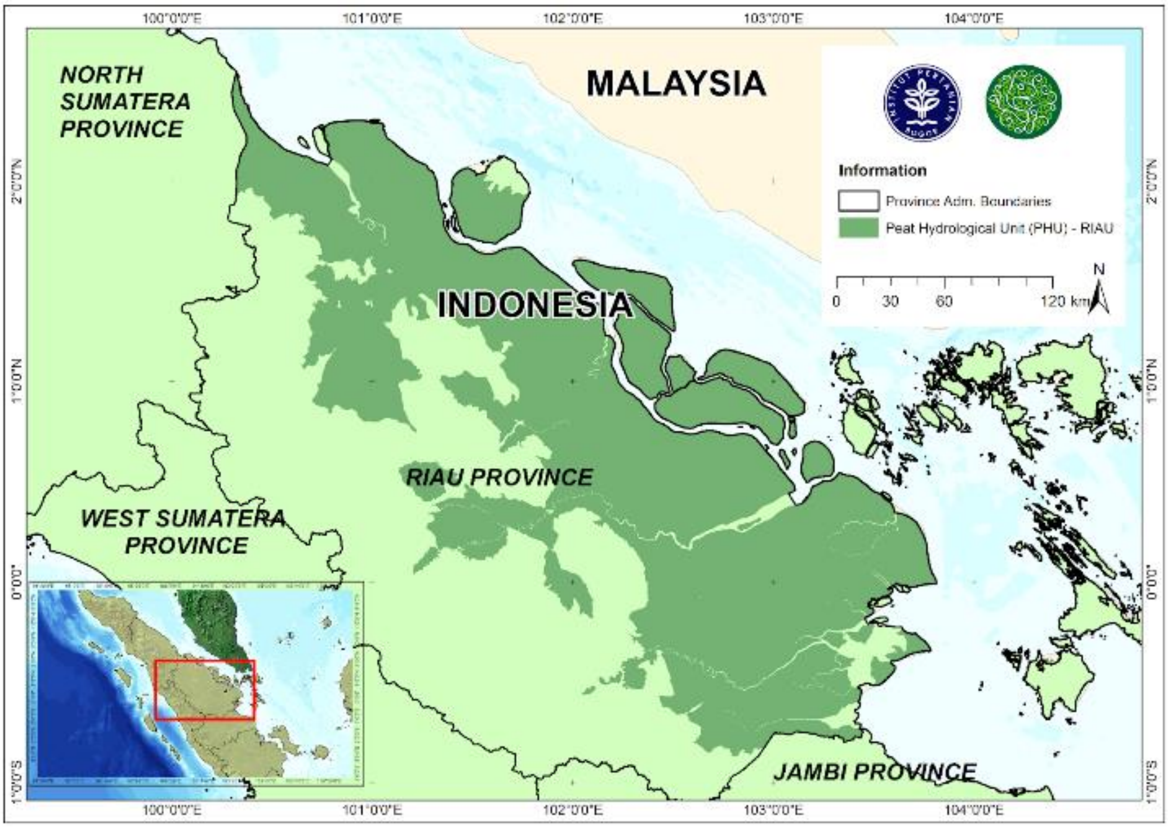

Figure 1. Research location

downloaded data is processed using ArcGIS software and clipped according to PHU Riau. Through ArcGIS, the number of hotspots in the PHU and non-PHU Riau areas can be calculated and known, so that the spatial pattern of hotspots in a location can be detected. The Sentinel-2 imagery taken to determine peat hydrology was taken from 2020 to 2024, this year was taken because it has low cloud cover so the detection results are more accurate. According to Mandanicii and Biteli (2016), Sentinel-2 imagery is a multispectral image with 13 bands and a spatial resolution ranging from 10 meters to 60 meters.

Peat Hydrological Unit

Sumatra has a peatland area of 20.6 million ha. 43% or 6.44 million ha (Wahyunto *et al.* 2014). Peatlands which are included in marginal land have developments where large changes in land use have occurred. The conversion of land from forests to plantations, agriculture, settlements and other physical infrastructure. The use of peat land for plantations ranks first (Wahyunto *et al.* 2013). Under these conditions, peatlands experience degradation in both quality and of course quantity. The inevitable impact is the emergence of disasters in peatland areas, namely in the form of land subsidence and forest fires. This is caused by disruption of peat hydrology, namely in the form of a decrease in ground water levels. The land subsidence was caused by drainage activities by making canals. The canals were built to maintain oxidation for the roots of plantation crops such as oil palm, rubber, etc. These plants cannot grow well if their roots are saturated with water (unaerobic) (Runtunuwu *et al.* 2011).

Peat hydrological unit (PHU) according to PP. No. 57 of 2016 is a peat ecosystem which is located between 2 (two) rivers, between a river and the sea, and/or in a swamp (Suwarno *et al.* 2016). Meanwhile, the peat ecosystem is the arrangement of peat elements which form a comprehensive whole that influence each other to form balance, stability and productivity. In a PHU it is always associated with peat domes, because peat domes according to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.14/MENLHK/SETJEN/KUM.1/2/2017 is a

PHU area that has a topography or relief that is higher than the surrounding area, so that it naturally has the ability to absorb and store more water, and can supply water to the area surroundings.

Hotspot Data

Hotspot monitoring is an important strategy in preventing forest and land fires. Therefore, to detect potential fires quickly, monitoring hotspots using technology such as the MODIS satellite is needed. MODIS (Moderate Resolution Imaging Spectroradiometer) will detect areas on the earth's surface that have a higher temperature than the surrounding temperature (Saharjo *et al.* 2015). A hotspot is a point in a location that has a relatively higher temperature compared to the surrounding temperature (Permenhut Number P.12/Menhut-ll/2009). Hotspots are also defined as indicators of forest and land fires. The more hotspots there are in an area, the more potential there is for fire incidents. However, hotspots do not always indicate forest fires. Hotspots that indicate a fire have several characteristics, such as a large number of hotspots clustered (close together) in an area, occurring for several days, and smoke appearing. Hotspots do not always indicate fires or have firespots, but hotspots are used as initial identification of forest and land fire incidents (Santriwati *et al.* 2021).

Table 1 Band of Landsat 8

Band	Band Name	Center Wavelength	Resolution
B1	Ultra Blue (Coastal aerosol)	433 nm	30 m
B2	Blue (B)	453 nm	30 m
B3	Green(G)	560 nm	30 m
B4	Red (R)	543 nm	30 m
B5	NIR	660 nm	30 m
B6	SWIR 1	865	30 m
B7	SWIR 2	773 nm – 793 nm	30 m

Climate Data

The data used in this research is annual rainfall data in Riau Province in millimeters (mm) taken in 2005-2023 on the NASA Power Access Data website. According to Pratamasari *et al.* (2020), rainfall (precipitation) is the amount of rain that falls in an area in a certain unit of time. POWER (Prediction of Worldwide Energy Resources) is a project from NASA (National Aeronautics and Space Administration) to predict rainfall and surface energy using satellites. The satellite used is a satellite with a passive system and has data availability from January 1, 1980 until now. The availability of NASA POWER rainfall data comes from the GCPC (Global Precipitation Climate Project) with a resolution of $0.5°C \times 0.5°C$ (Monteioro *et al.* 2017). In collecting rainfall data at NASA POWER, the Renewable Energy Daily Precipitation data type is used, which contains the intensity of daily rainfall.

Impact Data Analysis

Analysis of forest and land fire data was carried out using Landsat-8 image data adjusted to the area of interest and time of fire incident. The use of the RGB composite band with the SWIR-NIR-Red band allows the fire affected area, fire position and smoke direction to be detected. Landsat 8 is a satellite image launched by the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS). Landsat 8 has two sensors, namely the Operational Land Imager (OLI) and Thermal InfraRed Sensor (TIRS). Landsat-8 has 8 bands with a spatial resolution of 30 m – 100 m and a temporal resolution of 16 days (Chaves *et al.* 2020). The bands contained in Landsat 8 are presented in table 1.

RESULTS AND DISCUSSION

Peat Hydrological Unit (PHU) Condition in Riau Province

The service ecosystem of tropical peat swamp forests provides humans with ecological benefits, climate change mitigation, socio-economic benefits, and is important for biodiversity

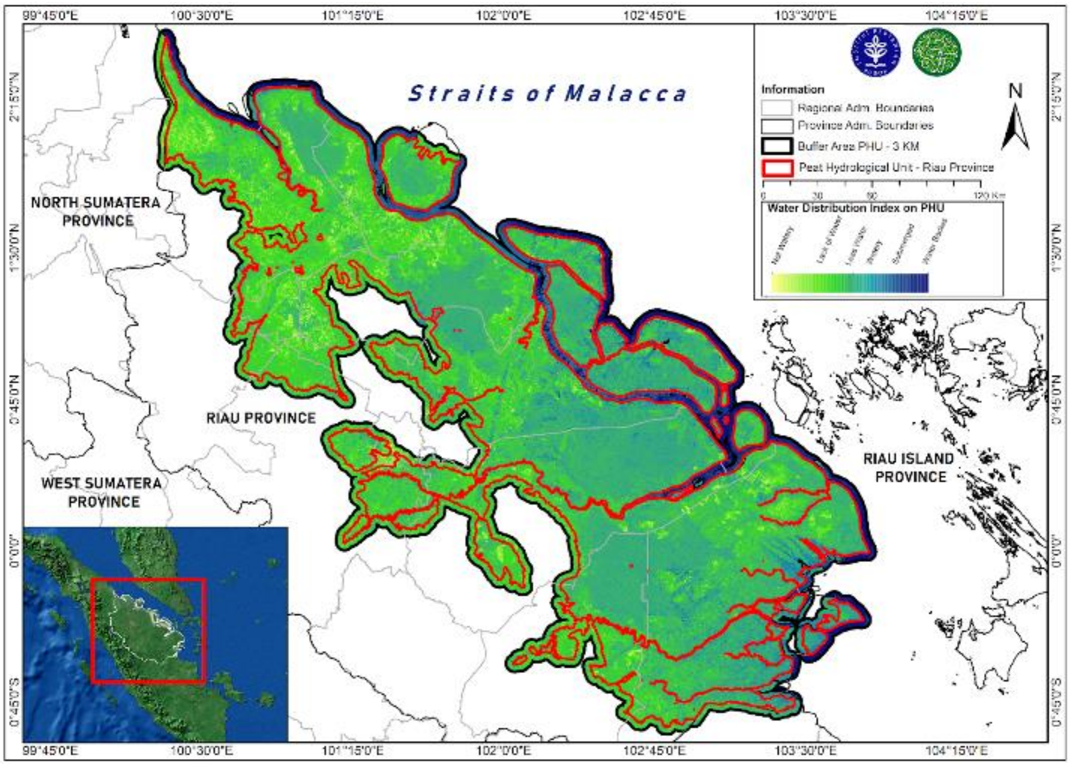

Figure 2. PHU condition in Riau Province

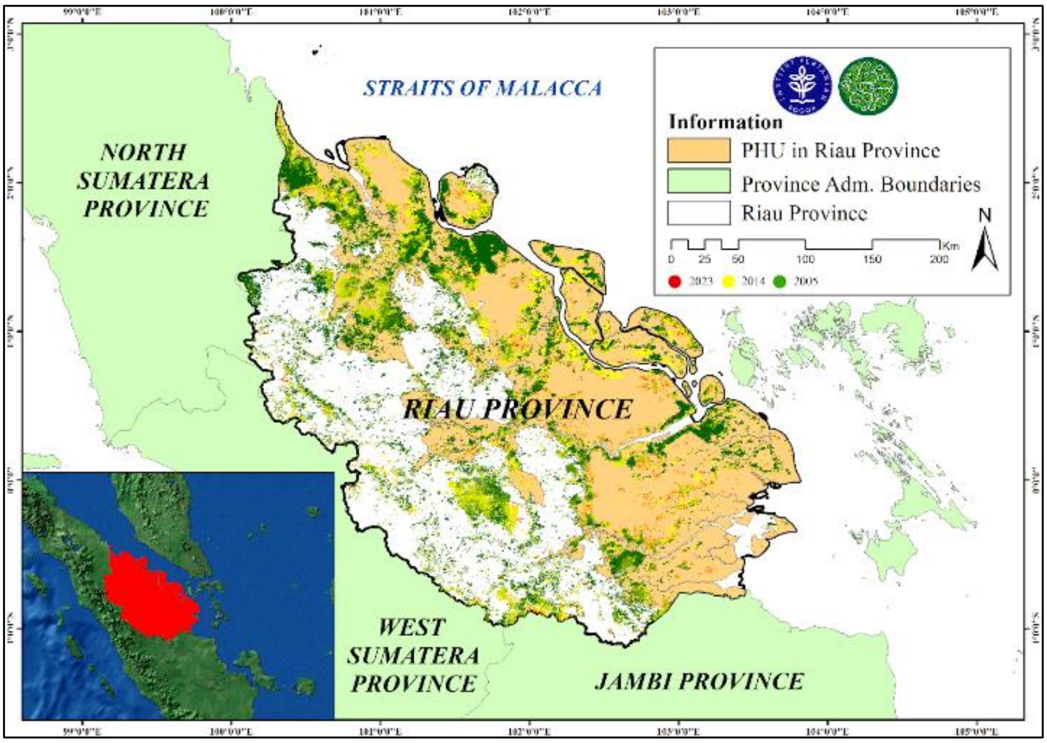

Figure 3. Hotspot distribution in Riau Province

(Harrison *et al.* 2020; Posa *et al.* 2011). The complex peat ecosystem poses a threat to various parties, especially communities who are vulnerable to disaster risks because of their low mitigation and adaptation capacity. Although globally, peatland fires are a high contributor to emissions, especially during El Niño (Liu *et al.* 2017), the vulnerability of local communities to understanding the concept of peat ecosystems requires mitigation efforts that are socially and economically inclusive.

The condition of the land in the Riau region is peat land with a total area of 4.04 million hectares or 56.1% of the peat land area in Sumatra (Irawan *et al.* 2022). The distribution of peat ecosystems in the Riau region is along the East Coast of Sumatra with varying depths ranging from shallow peat with a depth of 0.5 -1 meter, medium peat with a depth of 1-2 meters to very deep peat more than 4 meters (Suwondo *et al.* 2018). Most of the peat areas in this region are used for the development of Industrial Plantation Forests (HTI) and oil palm plantations (Forestry Service & Riau Province 2014). One of the largest PHUs in Indonesia is in Riau Province, namely the Kampar Peninsula PHU with an area of 722,929 ha (KepMenLHK Number SK.129/menlhk/setjen/pkl.0/2/2017). This PHU is an area that has very deep peat depth. According to Minister of Environment and Forestry Regulation Number P.14/MENLHK/SETJEN/KUM.1/2/2017, peat with a depth of more than 3 meters is peat that has a protective function. Utilization of peat ecosystems with this function is very limited and can only be carried out for knowledge-based activities such as research, education and management of environmental services.

Hotspot Distribution

Hotspots in the study area have been successfully detected using NASA FIRMS Hotspot data from 2005 to 2023. This hotspot includes the study area which is indicated as peat. Figure 2 depicts the hotspot points in 2005, 2014 and 2023 in Riau Province. 2005 had the largest distribution of hotspots compared to 2014 and 2023.

Groups of hotspots or hotspots that are large in number and clustered together and occur continuously can be indicated as actual fire incidents. During the period 2005-2023, the most hotspots were found in 2005-2015, while the fewest hotspots were found in 2016-2023. The spatiotemporal hotspot conditions can be seen visually in Figure 4.

The results of the analysis of the number of hotspot distributions obtained from FIRMS MODIS imagery identified in Riau Province during the 2005-2023 period are presented in Figure 5. Based on Figure 5, it can be seen that hotspot detection from 2005-2023 tends to decrease significantly. The highest number of hotspots was seen in 2005 with 29,722 points. Meanwhile, the lowest hotspot will be in 2022 with 827 points. In terms of accumulated data, hotspots are found in peat soil (PHU) as many as 138,523 points (77.8%), while in mineral soil (non PHU) there are 39,583 points (22.2%). The graph shows a trend of increasing the number of hotspots every 5 years, this increase in hotspots occurred in 2005, 2009, 2014 and 2019. The increase in the number of hotspots is thought to be caused by the El Nino phenomenon. According to Aflahah *et al.* (2019), under El Nino conditions, especially when combined with the Southwest Monsoon and cooler SST in Indonesian waters, the risk of forest and land fires increases significantly. The combination of dry conditions, high temperatures, and lack of rainfall creates an environment that is highly susceptible to fire. This drought occurs because differences in air pressure, water vapor that should blow towards Indonesia stops in the eastern Pacific so that rainfall in the western Pacific decreases (*Amatulloh et al.* 2024).

Furthermore, based on the distribution of the number of hotspot data shown in Figure 5, it also shows that the distribution of the number of hotspots in 2005 - 2023 in PHU areas is greater than in non-PHU areas. According to Wijaya *et al.* (2024), the PHU area has a peat dome feature, meaning that the land is located higher than the surrounding area, so naturally this area can accommodate and store more water and supply water to the surrounding area. Therefore, PHU is also an area that is very vulnerable to fire if there is an imbalance in its ecosystem. PHU that experiences degradation will cause rainwater to flow more quickly into rivers so that drought will occur quickly and it will easily catch fire. Forest and peatland fires are caused by the ease with which dry peat can burn. According to Kirana & Nurhayati (2022), dry peat land is good fuel for burning, the higher the water content in the peat, the lower the peat burning rate, the presence of El Nino conditions increases the chance of fire occurring.

Data on the distribution of hotspots is very important as an initial indication or prediction that a fire has occurred and is dynamic. Apart from being influenced by the flammable characteristics of peatlands, the distribution of hotspots is thought to follow certain patterns that are closely related to land cover conditions (Yusuf *et al.* 2019). The PHU area has areas that have experienced a lot of degradation. The damage that occurs to this ecosystem is caused by the belief that peat is useless land so it is often converted into agricultural land, plantations, settlements and other land which can have a negative impact on the peat ecosystem.

Riau has an equatorial type of rainfall, this rainfall is influenced by the Bukit Barisan and the influence of land and sea winds from the Malacca

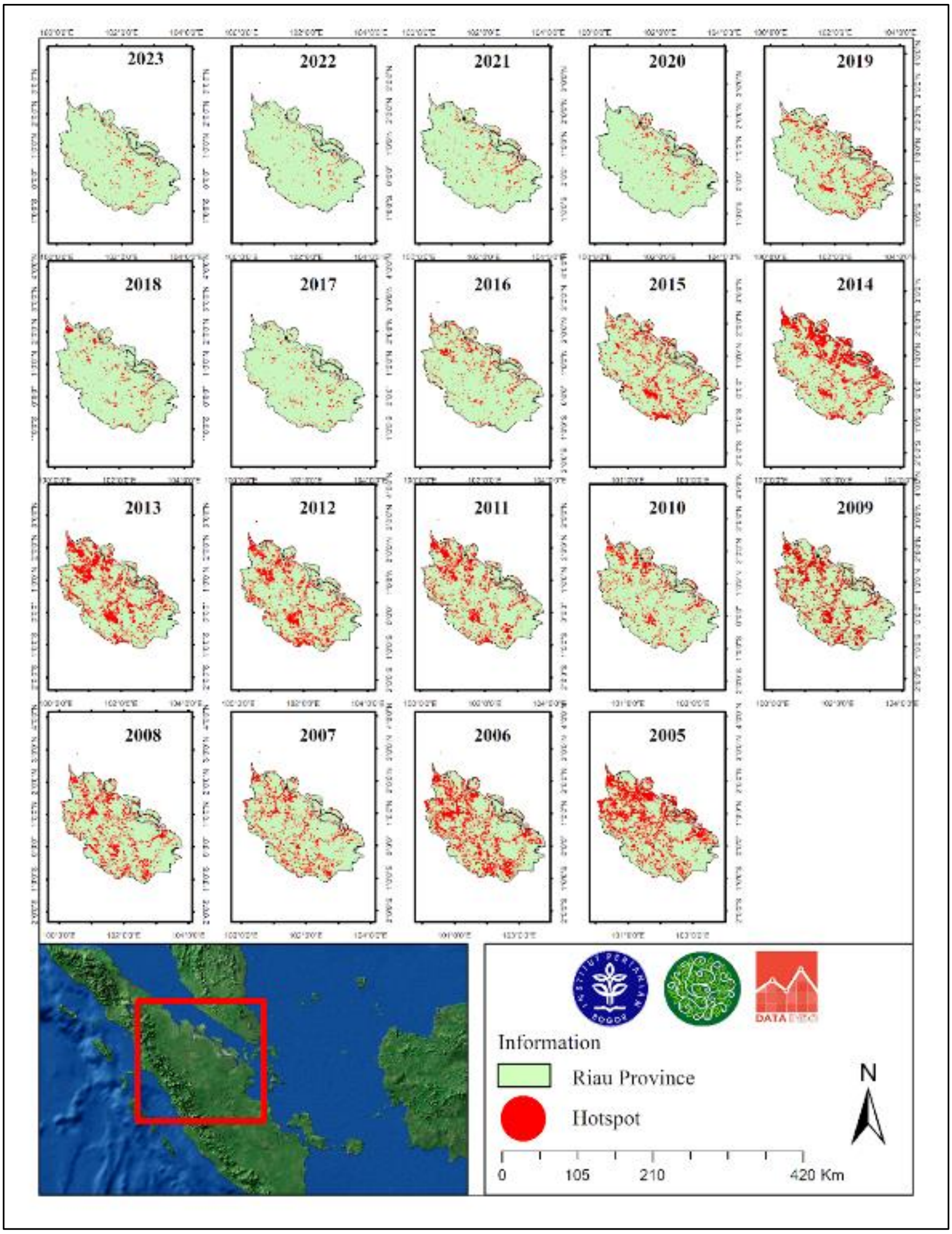

Figure 4. Hotspot spatiotemporal in Riau

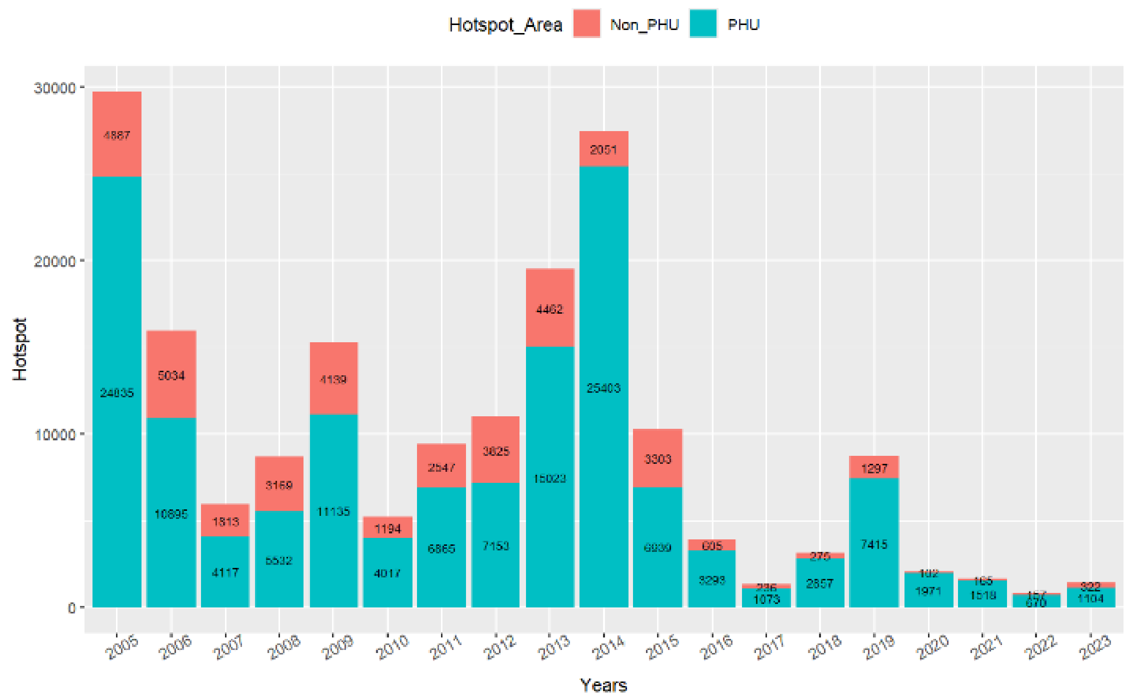

Figure 5. Hotspot in PHU and non PHU

Strait (Ardhitama & Sholihah 2014). This rain pattern has two peaks of rain that occur when the sun is close to the equator, namely around March and October. Based on annual rainfall data in Riau Province from 2005-2023, the amount of rainfall tends to increase from year to year. The largest rainfall occurred in 2021 and 2022 with amounts of 3146 and 3255 mm/year respectively, while the smallest rainfall occurred in 2015 and 2019 with amounts of 1960 and 1984 mm/year. The high or low rainfall that occurs in the area will influence the number of hotspots produced.

Rainfall and hotspots have an interrelated relationship. The image above shows the relationship between the number of hotspots and rainfall in the PHU and non-PHU areas. The intensity of rainfall will affect the number of existing hotspots. Based on figures 7 and 8, rainfall in 2005-2023 in the PHU and Non-PHU areas is fluctuating. The lowest rainfall in the PHU and Non-PHU areas occurred in 2015 at 1960 mm/year and the highest rainfall occurred in 2022 at 3255 mm/year. Rainfall will influence hotspot fluctuations in an area, where a high number of hotspots will be in harmony with low levels of rainfall (Dicelebica *et al.* 2022). However, the data obtained does not always show conformity with existing sources. Rainfall in PHU and Non-PHU areas has increased sharply in several years and is accompanied by an increase in the number of hotspots. The discrepancies in the resulting data may be caused by factors other than rainfall such as human activity, vegetation type, changes in land cover, and unsuitable environmental conditions. The type of land cover greatly influences the increase in hotspots.

Peat that has been damaged will find it difficult to return to its original condition even if wetting it. Therefore, even though Riau has an area where it often experiences rain during the rainy season so that the land is wet, it will still have a high number of hotspots. Anthropogenic factors such as humans also worsen the condition of peat. 99% of cases of forest fires in Indonesia that are indicated through hotspots are caused by humans. Apart from that, the number of hotspots is also influenced by land type. Figure 7 shows the relationship between rainfall and hotspots in PHU areas, while Figure 8 shows the relationship between rainfall and hotspots in non-PHU areas. According to Putri & Syaufina (2023), the large number of hotspots is influenced by the existence of large peat areas rich in organic material. There will be many hotspots appearing in the PHU area. Therefore, the PHU area has a high vulnerability to forest and land fire disasters.

Figure 6. Annual rainfall in Riau Province 2005-2023

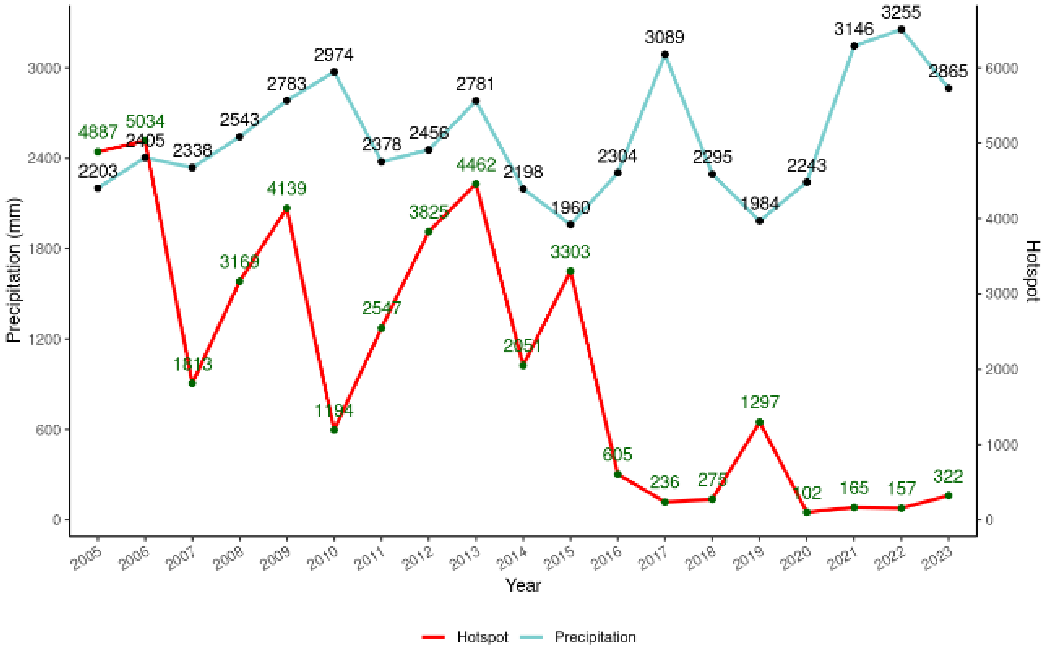

Figure 7. Relationship between rainfall and hotspots in PHU

Currently forest and land fires routinely occur every year in Riau Province. Based on Figure 9, it can be observed that the highest number of hotspots in Riau Province are in Rokan Hilir, Bengkalis and Pelalawan Regencies which are visualized through boxplots. In the dry season there are 4 districts/cities that are prone to fires, namely Rokan Hilir, Dumai, Bengkalis and Kampar (Syaufina *et al.* 2014). Hotspots can indicate fires, these three areas are the areas where fires occur most frequently. Most fires occur on land dominated by peat. Fires that occur on peatlands are more difficult to control because the fire spreads through above-ground biomass and in the subsurface layers of peat. Therefore, Riau Province, especially Rokan Hilir, Bengkalis and Pelalawan Regencies, is one of the areas that requires special attention in efforts to prevent forest and peatland fires (Yusuf *et al.* 2019). Meanwhile, the lowest

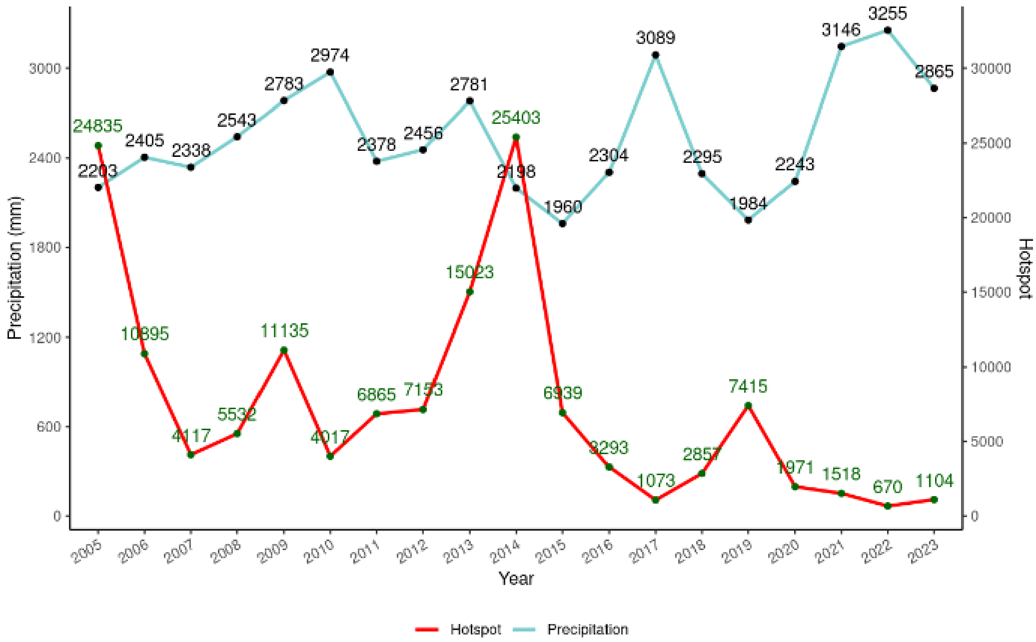

Figure 8. Relationship between rainfall and hotspots in non PHU

hotspot is in Pekanbaru City. Pekanbaru has a low number of hotspots because its area is small and is an urban area with a high population density. Apart from that, this region also does not have forest areas and is non-PHU.

Forest and Land Fire Impact

Peatland fires have negative impacts from an ecological, social and economic perspective. Forest fires can be graded based on three levels of severity, namely low, medium and high. The level of severity is seen from the condition of the vegetation and soil. Fires cause heat and an increase in temperature above 900-1150 degrees C. The heat generated from fires will be radiated underground, thereby causing an increase in temperature in the soil. This increase in temperature will have different impacts on the physical, chemical and biological properties of the soil.

Forest fires can cause previously dense canopies to become open, and the humus and litter layers are burned. This situation affects the physical properties of the soil, as changes in soil structure make it more prone to erosion, bulk density increases, and soil porosity decreases. Yulianti *et al.* (2023) stated that increased bulk density accelerates peat maturity, which in turn speeds up subsidence and CO_2 release. The higher the bulk density, the more compact the soil becomes, making it difficult for the soil to absorb and transmit water. Water deficiency in the soil causes it to dry out, which negatively impacts plants and microorganisms. A lack of water disrupts the chemical balance within plants, leading to decreased photosynthesis or disturbances in physiological processes. If this condition persists, the plant's health will deteriorate (Harwati 2007). In addition to affecting the soil's physical properties, fires also have a significant impact on its chemical properties. Forest fires can add minerals to the soil, with ash and charcoal from the burning process raising pH levels and increasing soil nutrients. However, this situation is short-lived because the open canopy increases erosion rates as the soil is no longer protected by vegetation. Besides affecting physical and chemical factors, fires also impact biological factors. Vegetation in peatlands plays an essential role in influencing biological conditions, particularly in the decomposition of litter and soil biota. According to Manurung *et al.* (2021), fires reduce the total number of microorganisms, fungi, and C-mic, all of which are crucial in the litter decomposition process. Changes in vegetation composition, particularly in post-fire lands, need to be considered to minimize damage to physical, chemical, and biological factors (Ward *et al.* 2015).

One of the social aspects caused by forest and land fires is the smoke, which can lead to

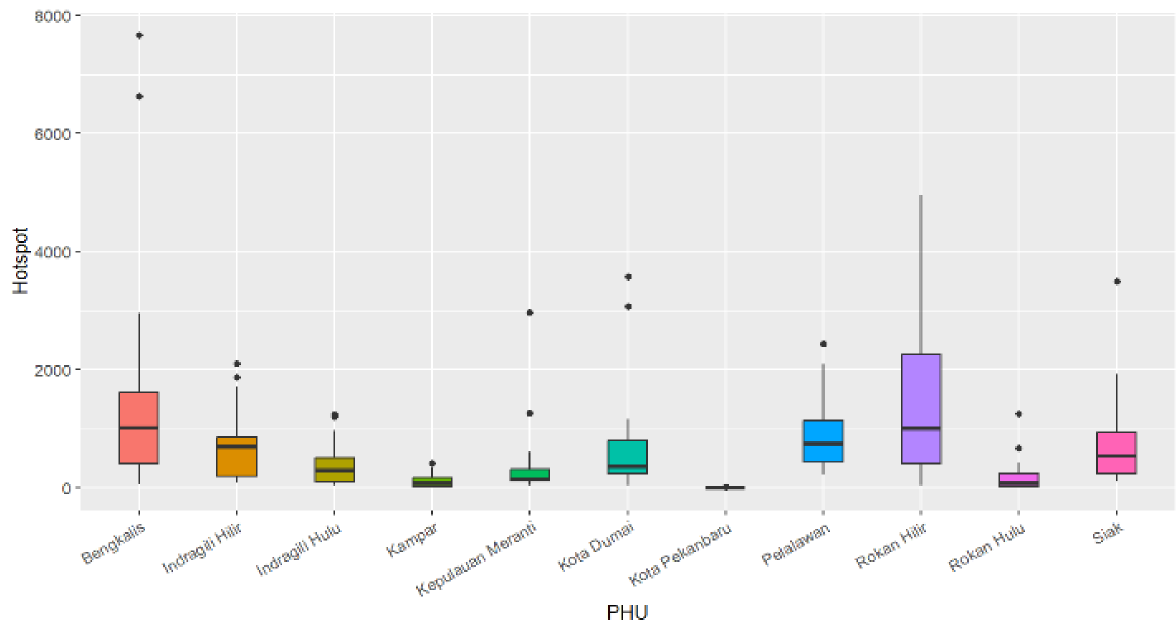

Figure 9. Hotspots in several regency

respiratory health problems such as Acute Respiratory Infections (ARI), bronchial asthma, bronchitis, pneumonia (lung inflammation), eye and skin irritation, and disruption to various human activities (Pasai 2020). The smoke produced by forest fires in peatlands emits carbon in the form of carbon monoxide (CO) and carbon dioxide (CO_2), which can cause serious irritation to the respiratory system (Irawan *et al.* 2022). Cases of Acute Respiratory Infections (ARI) in areas with high levels of pollution due to forest and land fires, especially in peat areas like Riau, tend to increase annually (Perwitasari & Sukana 2012). According to the Ministry of Health, the forest and land fires that occurred in 2015 in Riau Province were the worst in 18 years, causing severe air pollution in several countries, particularly in Southeast Asia, which shares a direct border with Riau (Yusuf *et al.* 2019). Based on Figure 10, there is an indication of fire and smoke detected in one of the districts, specifically in Bengkalis Regency, Riau Province, as seen through Landsat 8. The blue arrow shows the direction of the smoke, while the yellow circle indicates the presence of fire in the research area. The smoke detected in Bengkalis Regency is heading southwest, specifically toward the city of Pekanbaru and Duri Regency. These two areas remain covered in smoke due to winds generally moving to the southwest and south. The smoke in these two cities usually comes from neighboring areas prone to forest and land fires.

Figure 10. Fire and smoke detection in any of the areas

CONCLUSIONS

Monitoring of land fire hotspots in Riau was conducted from 2005 to 2023. Based on land type, hotspots were spread across two location types: PHU (peatland hydrological units) and non-PHU areas, with 138,523 hotspots (77.8%) in PHU areas and 39,583 hotspots (22.2%) in non-PHU areas. The highest number of hotspots was recorded in 2005 with 29,722 hotspots, and the lowest in 2022 with 827 hotspots. The decrease in hotspots over the years is attributed to the management of peatland damage, which has been addressed by the government, as well as policies that benefit peatland ecosystems. The use of FIRMS MODIS has proven effective in producing clear imagery for detecting hotspots. The distribution of hotspots is influenced by population size and, of course, the extent of PHU and non-PHU areas, with Pekanbaru having the fewest hotspots, while Rokan Hilir, Bengkalis, and Pelalawan have the highest, as they are predominantly PHU areas.

ACKNOWLEDGEMENTS

Thanks to IPB SSRS Association, which has facilitated the research.

REFERENCES

Amatulloh FW, Kanda ASK. **2024**. Pengaruh El Nino terhadap ekosistem dan ketahanan pangan masyarakat sekitar, (Studi kasus wilayah Margacinta Kec. Cijaura Bandung Jawa Barat). *Jurnal Ekonomi, Manajemen, dan Akuntansi* 2(2): 386-401.

Anhar IP, Mardiana R, Sita R. **2022**. Dampak kebakaran hutan dan lahan gambut terhadap manusia dan lingkungan hidup (studi kasus: Desa Bunsur, Kecamatan Sungai Apit, Kabupaten Siak, ProvinsI Riau). *Jurnal Sains Komunikasi dan Pengembangan Masyarakat* doi: 6(1):75- 85. https://doi.org/10.54783/ijsoc.v5i4.800.

Ardhitama A, Sholihah R. **2014**. Kajian penentuan awal musim di darah non ZOM 14 Riau dengan menggunakan data curah hujan dan hari hujan. *Jurnal Sains & Teknologi Modifikasi Cuaca* 15(2):65-73.

Arrafi M, Somantri L, Ridwana R. **2022**. Pemetaan tingkat keparahan hutan dan lahan menggunakan algoritma Normalized Burn Ratio (NBR) pada citra Landsat 8 di Kabupaten Muaro Jambi. *Jurnal Geosains dan Remote Sensing* 3(1):10-19. doi: https://doi.org/10.23960/jgrs.2022.v3i1.68.

Dinas Kehutanan Provinsi Riau. **2014**. Statistik Dinas Kehutanan Provinsi Riau 2014. Dinas Kehutanan Provinsi Riau.

Duryea ML., Landis TD. 1984. *Forest Nursery Manual: Production of Bareroot Seedlings*. New York: Oregon State University.

Harwati CT. **2007**. Pengaruh kekurangan air (*water deficit*) terhadap pertumbuhan dan perkembangan tanaman tembakau. *INNOFARM: Jurnal Inovasi Pertanian* 6(1):44-51. doi: https://doi.org/10.33061/innofarm.v6i1.247.

Harrison ME, Ottay JB, D'Arcy LJ, Cheyne SM, Anggodo, Belcher, C, Cole L, Dohong A, Ermiasi Y, Feldpausch T, Gallego-Sala, A. **2020**. Tropical forest and peatland conservation in Indonesia: Challenges and directions. *People and Nature* 2(1):4-28. doi: https://doi.org/10.1002/pan3.10060.

Irawan Y, Muzawi R, Alamsyah A. **2022**. Sistem real time monitoring pendeteksi kebakaran hutan dan lahan di Provinsi Riau. *Journal of Information Technology and Computer Science* 5(2):10-17. doi: https://doi.org/10.31539/intecoms.v5i2.4567.

KepMenLHK (Keputusan MenteriLingkungan Hidup dan Kehutanan) Nomor SK.129/MENLHK/SETJEN/PKL.0/2/2017 tentang penetapan peta kesatuan hidrologis gambut nasional.

Liu J, Bowman KW, Schimel DS, Parazoo NC, Jiang Z, Lee M, Bloom AA, Wunch D, Frankenberg C, Sun Y, O'Dell CW. **2017**. Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño. *Science 358*:6360-5690. doi: https://doi.org/10.1126/science.aam5690.

Mandanici E. Bitelli G. **2016**. Preliminary comparison of sentinel-2 and landsat 8 imagery for a combined use. *Remote Sensing.* 8: 10-14. doi: https://doi.org/10.3390/rs8121014.

Manurung R, Nusantara RW, Umran I, Warganda. **2021**. Kajian kualitas tanah pada lahan gambut terbakar di Kota Pontianak Provinsi Kalimantan Barat. *Jurnal Ilmu Lingkungan* 19(3):517-524. doi: https://doi.org/10.14710/jil.19.3.517-524.

Murtinah V, Edwin M, Bane O. 2017. Dampak kebakaran hutan terhadap sifat fisik dan kimia tanah di Taman Nasional Kutai, Kalimantan Timur. *Jurnal Pertanian Terpadu* 5(2):1-10. doi: https://doi.org/10.36084/jpt..v5i2.133.

Monteiro LA, Sentelhas PC, Pedra GU. **2017**. Assessment of NASA/POWER satellite-based weather system for Brazillian conditions and its impact on sugarcane yield simulation. International Journal of Climatology. doi: https://doi.org/10.1002/joc.5282.

Nakita C, Najicha FU. **2022**. Pengaruh deforestasi dan upaya menjaga kelestarian hutan di Indonesia. *Jurnal Ius Civile (Reflektansi Penegakan Hukum dan Keadilan)* 6(1):92-103. doi: http://dx.doi.org/10.35308/jic.v6i1.4656.

Pandia FS, Sasmito B, Sukmono A. **2019**. Analisis pengaruh angin monsun terhadap perubahan curah hujan dengan penginderaan jauh (studi kasus: Provinsi Jawa Tengah). *Jurnal Geodesi Undip* 8(1):278-289. doi: https://doi.org/10.14710/jgundip.2019.22581.

PerMenLHK (Peraturan MenteriLingkungan Hidup dan Kehutanan)Nomor P.14/MENLHK/SETJEN/KUM.1/2/2017 tentang tata cara inventarisasi dan penetapan fungsi ekosistem gambut.

Pratamasari A, Permatasari NKF, Pramudiyasari T, Manessa MDM, Supriatna. Spatial distribution patterns analysis of hotspot in Central Kalimantan using FIRMS MODIS Data. Jurnal Geografi Lingkungan Tropik 4(1):24-34. doi: https://doi.org/10.7454/jglitrop.v4i1.74.

Pasai M. **2020**. Dampak kebakaran hutan dan penegakan hukum. *Jurnal Pahlawan* 3(1):36-46. doi: https://doi.org/10.31004/jp.v3i1.609.

Perwitasari D, Sukana B. **2012**. Gambaran kebakaran hutan dengan kejadian penyakit ISPA dan pneumonia di Kabupaten Batang Hari, Provinsi Jambi Tahun 2008. *Jurnal Ekologi Kesehatan* 11(2):148-158.

Posa MRC, Wijedasa LS, Corlett RT. **2011**. Biodiversity and conservation of tropical peat swamp forests. *BioScience* 61(1):49-57. doi: https://doi.org/10.1525/bio.2011.61.1.10.

Saharjo BH, Putra EI, Syam N. **2015**. Pendugaan emisi gas rumah kaca akibat kebakaran hutan dan lahan pada berbagai tipe tutupan lahan di Provinsi Sumatera Selatan tahun. *Jurnal Silvikultur Tropika* 6(2):132-138. doi: https://doi.org/10.29244/j-siltrop.6.2.%25p.

Suwarno Y, Purwono N, Suriadi AB, Nahib I. **2016**. Kajian kesatuan hidrologis gambut wilayah Kalimantan Tengah. In *Ambar F, Dewayani, Nahib I, Narieswari L, Niendyawati,* *Riyadi B, Suwarno Y, Sur-yanta J, Turmudi (Editor). Seminar Nasi-onal Peran Geospasial dalam Membing-kai NKRI* (pp. 233-242).

Suwondo, Darmadi, Yunus M. **2018**. Perlindungan dan pengelolaan ekosistem: analisis politik ekologi pemanfaatan lahan gambut sebagai hutan tanaman industri. *Jurnal Pengelolaan Lingkungan Berkelanjutan* 2(2):140-154.

Ali I, Cao S, Naeimi V, Paulik C, Wagner W. 2018. Methods to remove the border noise from Sentinel-1 Synthetic Aperture Radar data: implications and importance for time-series analysis. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.* 11(6): 777–786. Doi: https://doi.org/10.1109/JSTARS.2017.2787650.

Runtunuwu E, Kartiwa B, Kharmilasari K, Sudarman K, Nugroho WT, Firmansyah A. **2011**. Dinamika elevasi muka air pada lahan dan saluran di lahan gambut. *Riset Geologi dan Pertambangan-Geology and Mining Research* 21(2):63-74. doi: http://dx.doi.org/10.14203/risetgeotam2011.v21.47.

Rasyid F. **2014**. Permasalahan dan dampak kebakaran hutan. *Jurnal Lingkar Widyaiswara* 1(4):47-59.

Santriwati, Halide H, Hasanuddin. **2021**. Faktor osean-atmosfer untuk memprediksi titik panas (*hotspot*) di wilayah Asia Tenggara Bagian Selatan. *Jurnal Geocelebes.* 5(2):116-130. doi: https://doi.org/10.20956/geocelebes.v5i2.13454.

Syaufina L, Hamzah AA. **2021**. Changes of tree species diversity in peatland impacted by moderate fire severity at Teluk Meranti, Pelalawan, Riau Province, Indonesia. *Biodiversitas Journal of Biological Diversity*. 22(5): 2899-2908. https://doi.org/10.13057/biodiv/d220555.

Syaufina L, Siwi R, Nurhayati AD. **2014**. Perbandingan sumber hotspot sebagai indikator kebakaran hutan dan lahan gambut dan korelasinya dengan curah hujan di Desa Sepahat, Kabupaten Bengkalis, Riau. *Jurnal Silvikultur Tropika* 5(2):113-118.

Taryono. **2021**. Analisis peran lahan gambut dalam perekonomian Provinsi Riau. *Jurnal Economica* 9(2):84-94. doi: https://doi.org/10.46750/economica.v9i2.46.

Wahyuni H, Suranto. **2021**. Dampak deforestasi hutan skala besar terhadap pemanasan global di Indonesia. Jurnal Ilmiah Ilmu Pemerintahan 6(1):148- 162. doi: https://doi.org/10.14710/jiip.v6i1.10083.

Wahyunto W, Nugroho K, Ritung S, Agus F. **2014**. Indonesian peatland map: Method, Certainty, and uses. di Prosiding Seminar Nasional Pengelolaan Berkelanjutan Lahan Gambut Terdegradasi untuk Mitigasi Emisi GRK dan Peningkatan Nilai Ekonomi. Indonesian Agency or Agricultural Research and Development, Jakarta, Indonesia (pp. 81-96)

Wahyunto AD, Pitono D, Sarwani M. **2013**. Prospek pemanfaatan lahan gambut untuk perkebunan kelapa sawit di Indonesia. *Perspektif* 12(1):11-22.

Ward SE, Orwin KH, Ostle NJ, Briones MJ, Thomson BC, Griffiths RI, Oakley S, Quirk H, Bardgett RD. **2015**. Vegetation exerts a greater control on litter decomposition than climate warming in peatlands. *Ecology.* 96(1): 113-123. doi: https://doi.org/10.1890/14-0292.1.

Wasis B, Saharjo BH, Putra EI. **2019**. Impacts of peat fire on soil flora and fauna, soil properties and environmental damage in Riau Province, Indonesia. *Biodiversitas Journal of Biological Diversity.* 20(6): 1770-1775. https://doi.org/10.13057/biodiv/d200639

Wijaya RA, Akbar AA, Romiyanto. **2024**. Pemetaan bahaya bencana kebakaran hutan dan lahan terhadap kesatuan hidrologis gambut (PHU) di Kabupaten Kubu Raya. *Jurnal Kajian, Penelitian, dan Pengembangan Pendidikan* 12(1): 516-530. doi: https://doi.org/10.31764/geography.v12i1.20988.

Xu J, Morris PJ, Liu J, Holden J. **2018**. PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. *Journal Catena.* 160:134-140. doi: https://doi.org/10.1016/j.catena.2017.09.010.

Yulianti L, Salampak, Jaya A, Sancho JJ. **2023**. Tinggi muka air dan bulk density pada tutupan hutan dan bekas terbakar di Provinsi Kalimantan Tengah. *Jurnal Penelitian UPR: Kaharatii* 3(2):74-82. doi: https://doi.org/10.52850/jptupr.v3i2.11045.

Yusuf A, Hapsoh, Siregar SH, Nurrochmat DR. **2019**. Analisis kebakaran hutan dan lahan di Provinsi Riau. *Jurnal Dinamika Lingkungan Indonesia* 6(2):67-84. https://doi.org/10.31258/dli.6.2.p.67-84.