ASSESSMENT OF FOREST DISTURBANCES USING REMOTE SENSING: CASE OF KALIWA RIVER FOREST RESERVE (KRFR), PHILIPPINES

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ABSTRACT:

The Kaliwa River Forest Reserve (KRFR) is located in the southwestern part of the Sierra Madre Mountain Range, Philippines. KRFR is one of the most important forest reserves in the country that is adjacent to urban areas and is very much affected by various forest disturbances. Forest disturbances can be caused by either anthropogenic or natural phenomena (e.g., typhoons, drought, and pathogen outbreaks) and may have negative effects on the forest structure and function. The study used the Normalized Difference Moisture Index (NDMI) in detecting forest disturbances for the period of 2010, 2015, and 2020. Results showed that the deforestation rate has significantly decreased from 6.22% in 2010 to 3.40% in 2020. The National Greening Program (NGP) and intensified forest protection activities of the Department of Environment and Natural Resources (DENR) may have contributed to the observed decreasing trend in deforestation rate. However, forest disturbance in the closed and open forest areas of KRFR gradually increased from 0.11% to 0.40%. Based on the accuracy assessment, the NDMI performed well in determining forest disturbances with mean values of 0.91 and 0.93 for completeness and correctness, respectively. The main contributor to forest disturbances in KRFR was mainly anthropogenic factors such as kaingin, illegal logging, urban sprawl, and upland farming. Outputs of this study can aid in the formulation of policies for better forest resource management, rehabilitation, and protection in the protected area.

1. INTRODUCTION

Forest disturbance is defined as an event causing that is relatively discrete which causes changes in the physical structure of vegetation and surface soil (Clarked, 1990; Solorzano and Gao, 2022). Forest disturbances can be caused by either anthropogenic or natural phenomena (e.g., typhoons, drought, and pathogen outbreaks) and may negatively affect the forest structure and function. Forest disturbance can be determined through the use of readily available spatial and temporal images of the Earth's surface provided by various satellites (Ochtyra, 2020).

The neighboring population benefits from various ecosystem services provided by bordering important ecological areas like forest reserves, national parks, and protected areas (Soriano et al., 2019). However, due to continuing urbanization, these vital areas have become very susceptible to degradation despite their significance. Anthropogenic activities such as basic subsistence, industrialization, and economic development contribute to forest degradation (Peñaranda et al., 2015). The Kaliwa River Forest Reserve (KRFR), Sierra Madre Mountain Range is one of the most vital forest reservations adjacent to urban areas that is very much affected by forest disturbances. The Sierra Madre Forest experienced forest losses from 2001 to 2010 (Perez et al., 2020; Dida et al., 2021).

In 1999, the KRFR has still 53.35% forest cover but significantly decreased in the following years (FMB-DENR 1999; Villegas & Pollisco 2008; Bucayu 2003; Laluan 2003; Vidal 2002; Malabrigo et al., 2014). According to DENR-B+WISER (2015), at least 408 hectares of natural forest per year were degraded as a result of various anthropogenic pressures such as illegal logging, land conversion, commercialization, and forest fires. Two (2) Executive Orders were created in response to forest degradation namely, the National Greening Program (EO 26) and the Total Log Ban on Natural and Residual Forests (EO 23).

Satellite remote sensing data has improved the processing and analysis of large and inaccessible areas hence, forest disturbance detection gives way to heterogeneous studies (Chen et al., 2021). One of the indices that is suitable for the detection of forest disturbances, in addition to the Normalized Difference Vegetation Index (NDVI) and Tasseled Cap Wetness Index (TCW), is the Normalized Difference Moisture Index or the NDMI (Lastovicka et al., 2020). Application of NDMI in the studies of Ochtyra (2020), Dida et al., (2021), and Zhang et al., (2016) was also able to detect forest disturbances.

A few studies were undertaken in KRFR such as assessment of biodiversity, carbon stock assessment, and watershed management. However, the integration of remote sensing and GIS in detecting the extent and rate of forest disturbances in a given period in the area has not yet been explored. Moreover, the study aims to determine the possible causal factors of forest disturbance and provide significant guidance for formulating better forest resource management, forest rehabilitation, protection plans, and policy-making in the protected area.

2. DATA AND METHODS

2.1 Study Area

The Kaliwa River Forest Reserve (KRFR) is located in the southwestern part of the Sierra Madre Mountain Range (14°39'55"N latitude, 121°22'42"E longitude) in the Philippines. It has a total land area of 34,380 hectares covering the Municipalities of General Nakar, Quezon on the northeastern side, and Tanay, Rizal on the southeastern part. The study area is an initial component under the National Integrated Protected Area System (NIPAS) and was proclaimed by virtue of Proclamation No. 573 in 1969 by then President Ferdinand E. Marcos. It is known to be the home of Dumagat Indigenous communities and important in the protection of various endangered wildlife species, mainly the Critically Endangered

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Philippine Eagle. The KRFR, its riparian forest in particular has high biodiversity value due to the presence of ecologically important plant species like Dipterocarps (Malabrigo et al., 2014).

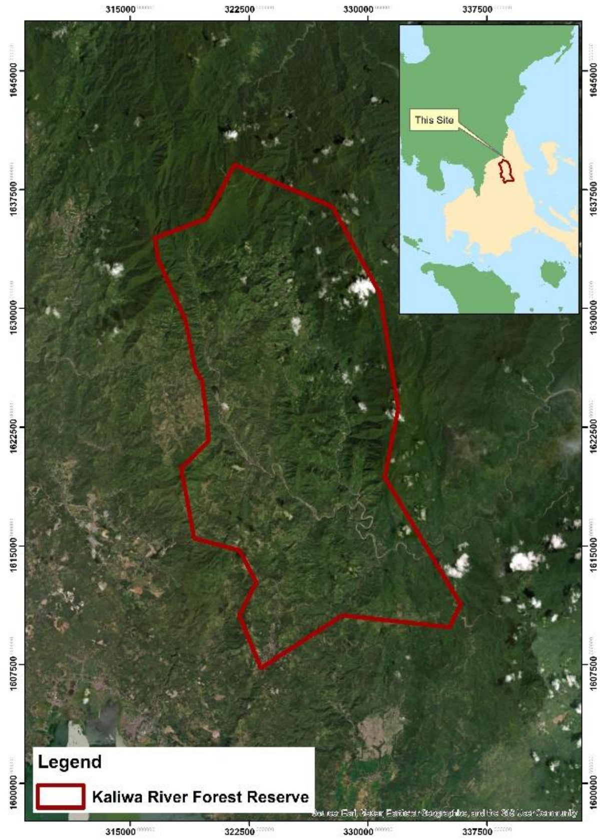

Figure 1. Location of the Study Area

2.2 Data used

The study used a satellite image provided by USGS Earth Explorer Survey specifically Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI-TRS (Operational Land Imager/Thermal Infrared Sensor) for the period of 2010, 2015, and 2020 as shown in Table 1. Images have less than 25% cloud cover with a spatial resolution of 30 meters. The image acquisition date was all in the same period to avoid seasonal variation. However, the study was not able to consider climatological factors that might affect the index values (i.e., rainfall data, and relative humidity).

Satellite	Sensor	Acquisition Date	Resolution
Landsat 5	TM	07/06/2010	30 m
Landsat 8	OLI/TIRS	07/20/2015	30 m
Landsat 8	OLI/TIRS	07/01/2020	30 m

Table 1. Landsat images used in the study.

The 2010, 2015, and 2020 Land Cover Map from NAMRIA and data on the LAWIN (Landscape and Wildlife Indicator) Forest Monitoring System were used in determining the possible causal factors of disturbance.

2.3 Methods

The general method as implemented in this study is shown in Figure 2. The Landsat images with less percentage of cloud cover and shadow undergo standard radiometric and atmospheric calibration. The cloud and cloud shadow were identified by visual interpretation of the images using the infrared band color combinations.

The Near-infrared band and shortwave-infrared bands were the inputs for the calculation of NDMI. The threshold level for disturbance and non-disturbance was extracted and underwent correctness and completeness accuracy assessment. The rate and distribution of forest disturbance will be determined based on the extracted threshold level. The possible causal factors will be ascertained using the land cover change analysis based on the NAMRIA Land Cover Map, and data from the Department of Environment and Natural Resources (DENR) Forest Monitoring System.

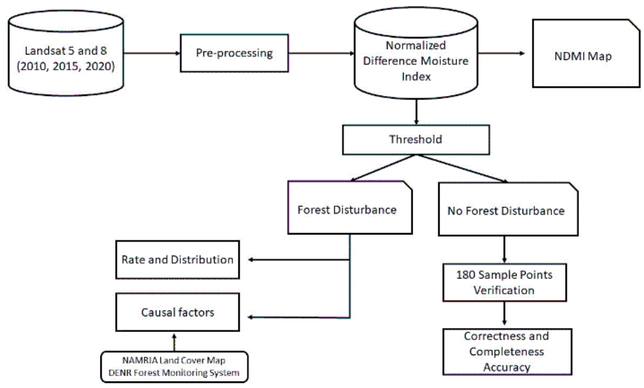

Figure 2. Flow Chart of the Method used in the study

2.3.1 Forest disturbance detection: Normalized Difference Moisture Index (NDMI) was used in detecting forest disturbances in KRFR. The NDMI (Normalized Difference Moisture Index) describes the vegetation's water stress level and is calculated as the ratio between the difference and the sum of the refracted radiation in the NIR and SWIR.

In Landsat 4–7, NDMI = (Band 4 – Band 5) / (Band 4 + Band 5).
In Landsat 8–9, NDMI = (Band 5 – Band 6) / (Band 5 + Band 6). (1)

The study used the image bands of Sentinel-2 that approximately correspond to particular Landsat bands, based on wavelength range. Index values of the disturbed forest (<0.28), and for the undisturbed (>0.37) were extracted following the works of Lastovicka et al., (2020) and used in determining the rate and distribution.

2.3.2 Accuracy assessment: To assess the accuracy of the employed methods, a total of 180 (60 each time series) sampled points were randomly selected and computed the correctness and completeness (Eq. 2) following Principe and Takeuchi (2019).

$$completeness = \frac{TP}{TP + FN}$$
$$correctness = \frac{TP}{TP + FP} \quad (2)$$

where *TP* are the true positives (selected disturbance is an actual disturbance); *FN* are the false negatives (selected no-disturbance

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is an actual disturbance); and *FP* are the false positive (selected disturbance is not an actual disturbance)

Google Earth Pro was used as the basis to support the interpretation process.

2.3.3 Causal factor of disturbance: A land cover change (2010-2015 and 2015-2020) was generated using the NAMRIA Land Cover Map using vector overlay analysis. The closed and open forest that was converted into other land cover types were extracted and analyzed.

Moreover, data from Landscape and Wildlife Indicators Forest and Biodiversity Protection System or LAWIN from DENR Region IV-A was used in determining the possible causal factor and also served as validation of the remotely-sensed disturbance. LAWIN is a web-based monitoring tool on forest cover change, indicator species, and forest and biodiversity threats to design management plans for conservation areas. Foresters and Forest-rangers recorded the observed disturbances and threats during their foot patrol and monitoring in their respective area of responsibility.

3. RESULTS AND DISCUSSION

3.1 Forest Disturbances in KRFR

The normalized difference moisture index (NDMI) values for 2010 ranged from -0.27 to 0.74. For 2015, the NDMI values ranged from -0.05 to 0.56, and for 2020, NDMI values ranged from -0.30 to 0.63 (Figure 3). Areas with low or negative values have low canopy cover and with water stress are expected to be disturbed areas while highly vegetated areas with no water stress are expected to have a high NDMI value (Gao, 1996; Dida et al., 2021).

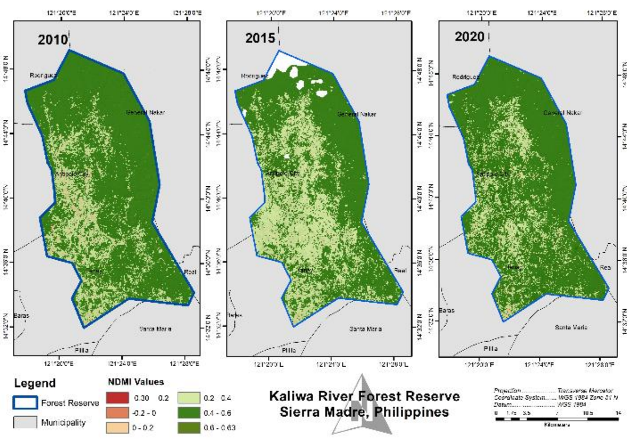

Figure 3. NDMI in KRFR based on Landsat 5 for 2010 and Landsat 8 for 2015 and 2020

The forest disturbance remarkably decreased from 6.22% in 2010 to 3.40% in 2020. The National Greening Program (NGP) and intensified forest protection activities of DENR and other concerned government agencies and private organizations may have contributed to its decreasing trend. However, forest disturbance in the closed and open forest areas of KRFR gradually increased from 0.11% to 0.40% (Figures 4 and 6).

The highest forest disturbance occurrence was observed in 2010 with approximately 6.22% of the total area or about 2,139.94 hectares. The observed disturbances were more clustered in the southwestern part of the KRFR and in large sizes with an average area of 0.8919 hectares. On the other hand, the forest disturbances observed for 2015 and 2020 are in small patches and sporadically distributed in the area and progressed in the northeastern part of the area (Figures 4 and 5).

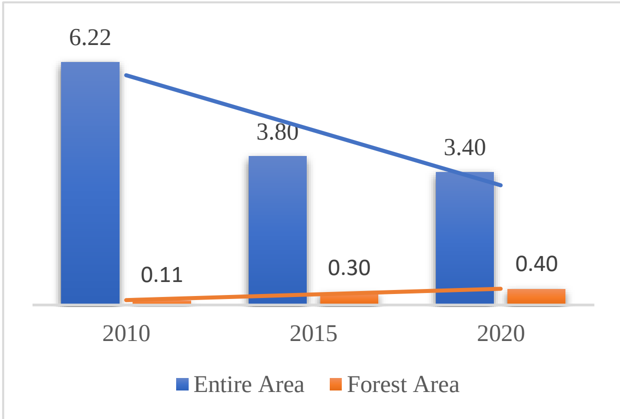

Figure 4. Percentage of forest disturbance in KRFR

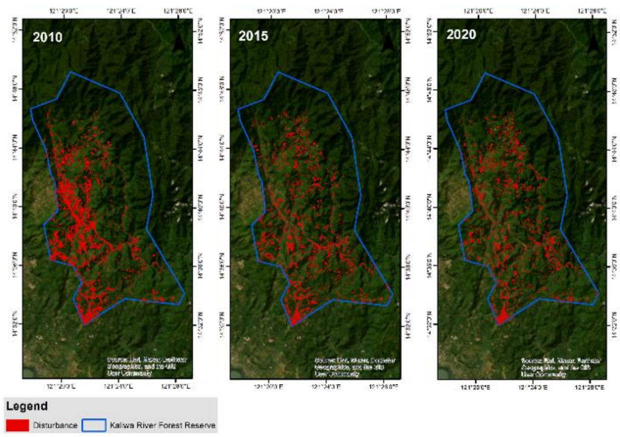

Figure 5. Forest Disturbances in KRF

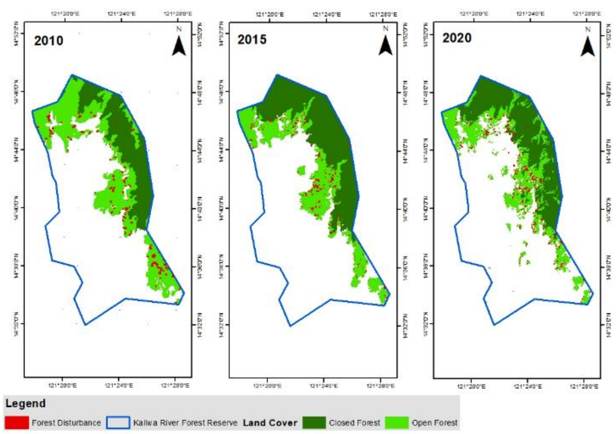

Figure 6. Forest Disturbances in KRFR's Closed and Open Forests based on the NAMRIA Land Cover Map.

Moreover, 363 hectares were detected as disturbed areas in 2010 and remained disturbed in 2020. Meanwhile, approximately 1,777 hectares were detected as disturbed areas in 2010 and undisturbed in 2020. Further, newly disturbed areas of approximately 807 hectares were detected in 2020 and not observed in 2010.

Nonetheless, KRFR still has a higher endemicity, and a notable number of species than most of the declared Key Biodiversity Areas (KBAs) in the Philippines despite the widespread disturbances (Malabrigo et al., 2014; Ambal et al., 2012).

3.2 Accuracy Assessment

The results of the performed accuracy assessment of the extracted forest disturbance following the threshold used by Lastovicka et al., (2020) are shown in Table 2. In general, the NDMI performed well in determining forest disturbances. It incurred an average of 0.91 and 0.93 in completeness and correctness, respectively. Despite the high accuracy, most of the false positives were observed in the inland water areas and riverbanks while brush and shrubs areas were classified as non-disturbed areas. Hence, actual validation of the sampling points is necessary.

Year	Accuracy Parameters	
	Completeness	Correctness
2010	0.93	0.90
2015	0.91	0.97
2020	0.88	0.93

Table 2. Accuracy assessment results for extracted forest disturbance.

3.3 Causal Factors of Forest Disturbance

3.3.1 Land Cover Change: Approximately 1,214.44 hectares of forest (open and closed) land cover were converted to other land cover classes from 2010 to 2015 (Figure 7). Approximately 96% or 1,169.07 hectares of this were converted into brush/shrubs, grassland, and perennial crops which indicates kaingin or agricultural land conversion in the area. Occurrences of human occupation in the forest areas of KRFR were observed with an estimated area of 1.12 hectares.

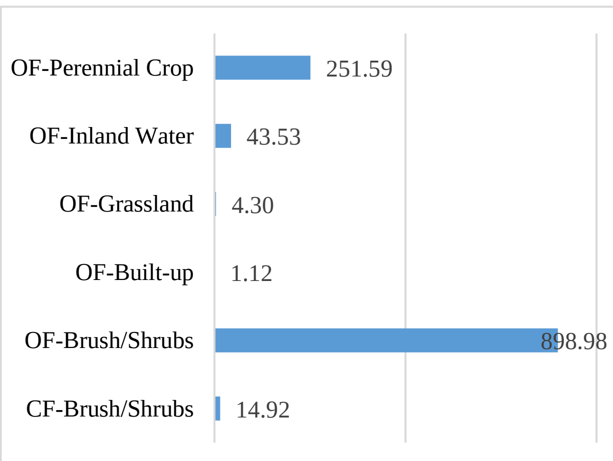

Figure 7. Land cover changes in KRFR from 2010 to 2015. OF = Open Forest; CF = Closed Forest.

From 2015 to 2020, an estimated 1,443.04 hectares of forest (open and closed) land cover was converted to other land cover classes (Figure 8). Most of the areas were predominantly converted into brush/shrubs. Moreover, the conversion of forests to open/barren areas can be observed, which indicates intensive forest landscape degradation. The same results were also reported in the study of Perez et al., (2020) wherein significant losses in both open and closed forest cover were observed even with the ongoing National Greening Program.

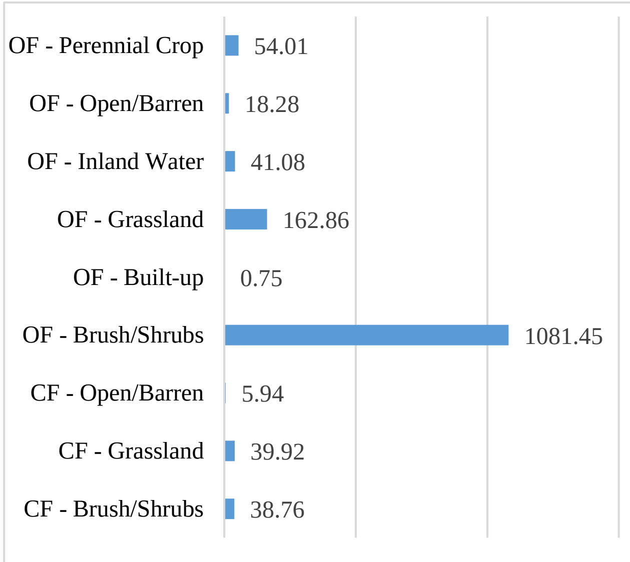

Figure 8. Land cover changes in KRFR from 2015 to 2020. OF = Open Forest; CF = Closed Forest.

3.3.2 Forest Monitoring System: Based on the recorded observed threats through forest monitoring and patrolling of DENR personnel, kaingin, illegal logging, urban sprawl, and upland farming were reported to be the main contributors to forest disturbances in KRFR (Figure 9). Illegal timber poacher engaged their activity in the remaining residual forest while Dumagat natives also contributed to forest degradation through fuelwood gathering, kaingin, and charcoal-making (Malabrigo et al., 2014). Forest disturbance driven by natural factors involves only typhoons and rain-induced landslides.

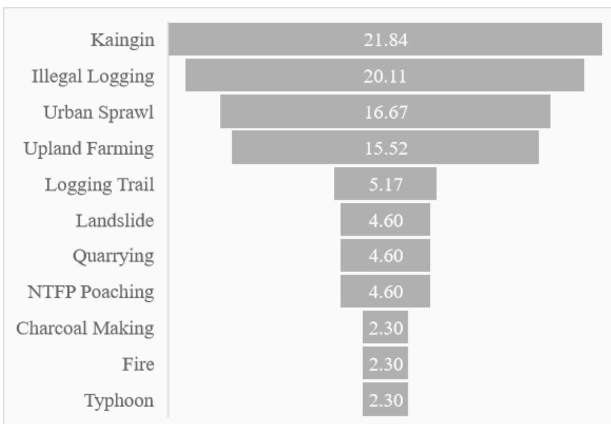

Figure 9. Drivers of forest disturbance in KRFR based on the Forest Monitoring and Patrolling System of the DENR.

Additionally, the detected forest disturbance agrees with the observed threats and disturbance of DENR as shown in Figure 10. However, there were detected forest disturbances in the northern and eastern parts, particularly in the remaining forest area of KRFR that is outside the patrol routes of forest rangers.

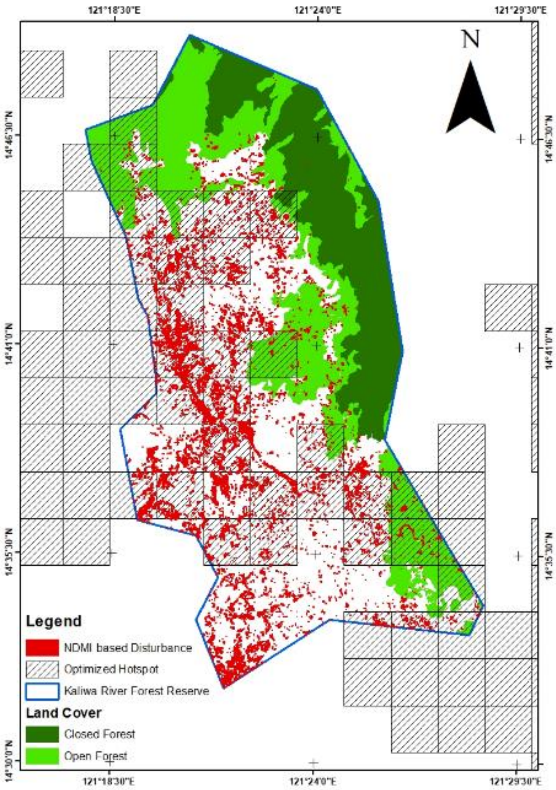

Figure 10. Hotspot Areas within KRFR.

4. CONCLUSION AND RECOMMENDATIONS

This study has demonstrated the potential use of remote sensing in detecting forest disturbance in a forest reserve. NDMI performed well in detecting forest disturbance based on the generated values of the said index.

The observed disturbances through the generated NDMI agreed with the land cover change based on the land cover map from NAMRIA and forest protection and monitoring data from DENR. The main contributor to forest disturbances in KRFR was mainly due to anthropogenic factors such as kaingin, illegal logging, urban sprawl, and upland farming. Disturbances caused by natural factor only includes typhoons and rain-induced landslides.

Forest monitoring and protection should extend the patrolling in the remaining residual forest area of KRFR due to increasing occurrences of disturbance.

The methodology proposed in this study can be used in other related studies including pest infestation and rainfall-induced landslide. It is also highly recommended to conduct a ground survey to validate the results. Lastly, exploring more complex time series analysis (i.e., semi-annual or annual), and other techniques (e.g., machine learning algorithms) could also be done to improve the detection and conduct simulations on forest disturbance.

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