

The Use of Sentinel-2 Data in Detecting Brown Spot Needle Blight in Loblolly Pine

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Abstract

Over the last several years, pine forests in the southeastern United States have been impacted by needle disease, commonly referred to as Brown Spot Needle Blight (BSNB). This has impacted large areas of pine plantations, and while the short- and long-term impacts are still being studied, it is thought to at least be causing growth reductions, and in several cases, widespread mortality has been reported. The first visual signs are browning needles, which occur at the bottom of the crown first and progress upwards. This study seeks to leverage remotely sensed data and derived image indices to assess the possibility of detecting and tracking foliar changes using a time series of image indices in a pine forest impacted by BSNB. The image indices calculated were used to track growing-season changes, which are found to decrease as the needle disease impacted the forest. This method could be enhanced on monthly or greater time scales to provide forest managers with a means of early detection that would allow them to employ measures to mitigate spread.

Keywords

Brown Spot Needle Blight, Image Indices, TGI, NDVI, VARI, Loblolly Pine

1. Introduction

Pine forests are an economically important species in the southeastern United States, an area commonly referred to as the nation's wood basket for the amount of pine pulp and sawtimber produced there. In this region, pine forests are susceptible to multiple disturbance agents such as drought, wind, ice, insects, and pathogens, which strike with varying frequency and lead to a range of impacts. With regard to pathogens, one has recently emerged with region-wide presence and is referred to as brown spot needle blight (BSNB), caused by *Lecanosticta acicola*.

This is not new, having first been identified nearly 150 years ago (de Thümen, 1878) and found to impact more than 50 species of pine throughout the world (van der Nest et al., 2019). In the southeastern U.S., BSNB has been found for approximately 100 years and has impacted economically important species such as Loblolly pine (*Pinus taeda*), Longleaf pine (*Pinus palustris*), and Shortleaf pine (*Pinus echinata*) (Hedgcock, 1929; Siggers, 1944). It first presented in nursery stock, which led to planting failures in Texas (Hedgcock, 1929), but for many years was thought to primarily impact longleaf pine (Siggers, 1944). Phelps and others (1978) reported that BSNB led to timber growth reductions of approximately 16 million ft³.

Brown spot needle blight has received increased attention in the southeastern United States as it has been aggressively spreading through both natural and anthropogenic processes. Similar to recent introductions in parts of Europe, sexual reproduction is producing wind-blown spores, allowing for more natural spread (Janoušek et al., 2016; van der Nest et al., 2019). Wind-blown spores are not new in the southeastern U.S., with annual spore detection in longleaf pine being reported over 50 years ago in Mississippi (Kais, 1971). Recently, BSNB has been identified in loblolly pine plantations, which are the most widely commercially planted species in the region. While historically, the concern has been BSNB impacting seedlings (Siggers, 1944), it is now impacting more mature trees, with growth reductions reported in multiple states. A lack of production in this region could have detrimental impacts on the forest products industry, affecting wood quality and quantity. These issues could impact wood supply in the region and affect timber value and prices of finished products. The region also typically has mild winters, particularly in more southerly latitudes, and ample rainfall. This has historically been ideal for spore production, particularly in times of rainfall following dry periods (Kais, 1971).

It is difficult to identify BSNB as there are multiple agents that can cause the needle yellowing and spotting associated with BSNB. A couple of methods have been developed to isolate the pathogen producing BSNB, the most widely used being Polymerase Chain Reaction (PCR) (Ioos et al., 2010; van der Nest et al., 2019; Sims et al., 2025). Samples, though, typically are not obtained until there are visual signs of an issue. Trees impacted by BSNB typically begin showing symptoms in the bottom of the crown. As it progresses, more needles begin to brown and eventually needle cast occurs. This means that by the time visual symptoms appear, BSNB has likely spread throughout the stand and into adjacent forests. To assess subtle changes in the health of trees in a stand or forest, remotely-sensed data can be leveraged as a tool to identify areas of subtle shifts in plant health and productivity.

The use of imagery acquired from satellites provides a repeatable, consistent record of reflectance values for a given area. Reflectance values from satellite data can be utilized over time to identify and track disturbance causing forest health issues (Wilkinson & Crosby, 2010; Hart & Veblen, 2015; Abdullah et al., 2019;

Crosby et al., 2024). The objectives of this study are to calculate image indices using remotely sensed data and to construct a time series to assess health declines related to BSNB in Louisiana, in the southeastern United States. Establishing this methodology could provide forest health managers with a means of determining forest health issues before they present visually and allow management decisions to prevent spread and impacts on timber production.

2. Methods

An area in Shongaloo, LA (**Figure 1**), was confirmed to have BSNB with a severity rating of 30 - 50% based on field-based assessment. Needle and litter samples were obtained and Polymerase Chain Reaction (PCR) analysis was performed in May 2024 at Louisiana Tech University, confirming the presence of *Lecanosticta acicula* (Sims et al., 2025). Cloud free Sentinel-2A imagery was then acquired to represent the growing and non-growing seasons (generally June and December) from 2016 to 2023. These times were chosen as they reflect when photosynthetic processes are most and least efficient (McGregor & Kramer, 1963). These two months are also in two distinct seasons for growth, with June being peak growing season. This provides the ability to assess seasonal variation and isolate any growing season trends in overall health. The L2A product was utilized as this provides atmospherically corrected, bottom of atmosphere reflectance values. The sensor covers 13 spectral bands at three different spatial resolutions and is freely available. For each image, the visible (blue, green, red) and NIR bands were selected because of the 10 m spatial resolution available. Once the data were downloaded, ArcGIS Pro 3.2 was used for image processing. The spectral bands selected were utilized to calculate image indices that are commonly related to plant health and productivity.

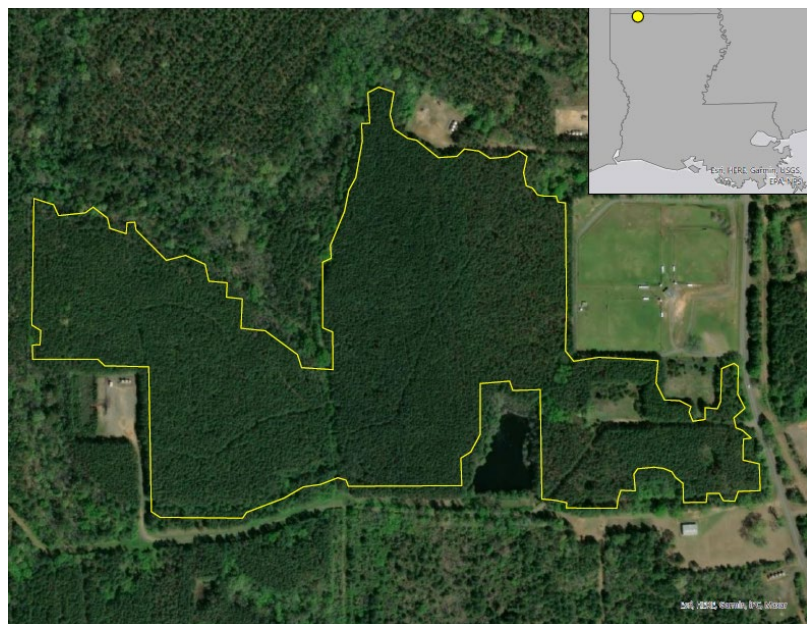


Figure 1. Study site in Shongaloo, LA, showing three stands used to assess Spectral changes and BSNB presence.

A common index is the Normalized Difference Vegetation Index (NDVI), which is calculated as a ratio of the difference in NIR and red reflectance (Equation (1)). Forest biomass is correlated with NDVI values, although it can saturate at values closer to one. The Visible Atmospherically Resistant Index (VARI) utilizes the visible reflectance bands, and the ratio (Equation (2)) mitigates atmospheric impacts and emphasizes vegetation and is related to leaf area. The Triangulated Greenness Index (TGI) (Hunt et al., 2013) is related to chlorophyll content and is calculated as the area of the triangle defined by visible red, green, and blue reflectance (Equation (3)).

$$\text{NDVI} = \frac{(R_{\text{NIR}} - R_{\text{red}})}{(R_{\text{NIR}} + R_{\text{red}})} \quad (1)$$

$$\text{VARI} = \frac{(R_{\text{Green}} - R_{\text{red}})}{(R_{\text{Green}} + R_{\text{red}} - R_{\text{Blue}})} \quad (2)$$

$$\text{TGI} = -0.5 * [(\lambda_{\text{Blue}})(R_{\text{Red}} - R_{\text{Green}}) - (\lambda_{\text{Red}} - \lambda_{\text{Green}})(R_{\text{Red}} - R_{\text{Blue}})] \quad (3)$$

where R_x represents the reflectance of the respective band (NIR, red, green, or blue) and λ_x are the central wavelengths for each band (red, green, or blue) (Hunt et al., 2013).

After defining the study area, each image (growing and non-growing season) was extracted to the study area and the three indices were calculated. All indices were then converted to NetCDF and combined into a mosaic dataset with the date of each image (month/year) added as a variable. A multidimensional dataset was then created using the mosaic dataset with the chosen index (NDVI, VARI, or TGI) and time set as the dimensions. For each index mosaic, plots were allocated, and values were extracted using a fishnet tool in ArcGIS Pro. The plots were systematically allocated to ensure coverage throughout the forest with a spacing of approximately 60 meters between locations. The plot locations allowed for the creation of temporal profiles and extracted values used to determine the percent change over the assessed time period.

3. Results

Observationally, browning of needles was observed in 2019 but less so in 2020; however, between 2020 and 2022, the browning of needles intensified, which was followed by needle casting throughout the property. The averaged values for 57 sampled locations for each time period reflect a seasonality with slight fluctuations in index values (Figures 2(a)-(c)), which would be expected. However, over the time frame assessed, there is a general decline in each index, following peaks in each index in 2018-2019. The Mann-Kendall trend test ($\alpha = 0.1$) reveals a significant decreasing trend for all indices. NDVI peaks at approximately 0.5 in 2019, which coincides with the onset of browning when no previous issues were observed on the property. Overall, VARI values were low but decreased by 12 - 15% when needle casting began due to the reduction in fractional vegetative cover. Considering TGI, the seasonal signal remains consistent with the decreased chlorophyll

content during the winter months. TGI fluctuations, as a percentage, were generally between the values of NDVI and VARI (Table 1).

Part of the property was thinned in 2015-2016, which is reflected in growing-season decreases in NDVI, VARI, and TGI, followed by an expected recovery as growth release occurs in 2018-2019 (Table 1). Between 2018 and 2019, VARI and TGI decrease before recovering slightly, then the decrease in all three indices deepens between 2020 and 2022. The growing-season TGI value decreases starting in 2020 and continues through 2024, whereas NDVI and VARI increase between 2022 and 2023. Understory growth was observed on the property following the thinning and again between 2022-2023 as needle cast occurred. Between 2023-2024, the values of all indices decrease precipitously as a timber harvest began on the property while BSNB continued to impact the forest.

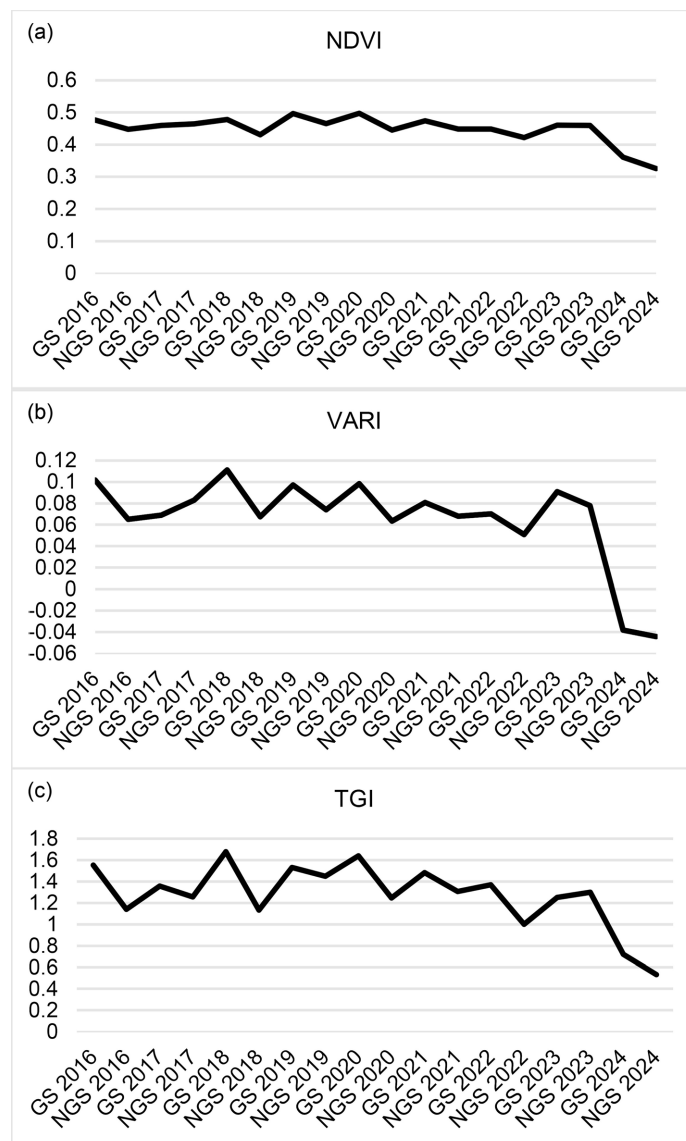


Figure 2. Trend in growing and non-growing seasons indices NDVI (a), VARI (b), and TGI (c) between 2016 and 2024.

Table 1. Year-to-year changes in average growing season image indices from sample locations.

Year	Index (% Change)		
	NDVI	VARI	TGI
2016	0	0	0
16 - 17	-3.6	-32.1	-12.6
17 - 18	4.1	61.2	23.7
18 - 19	3.8	-12.7	-8.8
19 - 20	0.2	1.3	7.1
20 - 21	-4.7	-17.9	-9.5
21 - 22	-5.4	-13.1	-7.6
22 - 23	2.7	29.5	-8.6
23 - 24	-24.6	-137.6	-42.5

4. Discussion

The image indices utilized in the present study depict changes consistent with observed needle and crown issues in the forest. NDVI is a widely used index for assessing and tracking biomass in forests (Lefsky et al., 2001; Peduzzi et al., 2010; Puliti et al., 2021; Herraiz et al., 2023) and is also a commonly used variable in modeling losses following disturbance (Yan et al., 2025). NDVI did not show decreases at the level VARI and TGI do in this study; however, the decreases calculated in the present study from 2020 through 2022 would be consistent with biomass loss, such as that from needle cast. The increase in all indices from 2022 to 2023 is due to increased light availability in the understory and the flush of understory vegetation.

The use of VARI and TGI was undertaken as these indices are commonly linked with fractional vegetation coverage and chlorophyll content, respectively. The idea is that VARI would be more sensitive to leaf area changes as needle cast occurred. This is indicated as VARI experienced the greatest percent decrease. Considering only visible reflectance makes VARI a convenient index to calculate, and its accounting for atmospheric influence by including blue reflectance has made it highly accurate in determining the extent of vegetation (Gitelson et al., 2002; Govedar & Anikić, 2024). Future research should consider the use of VARI with high-resolution image acquisitions such as those from unoccupied aerial vehicles (i.e., drones). This has been done in agricultural applications with promising results for developing site-specific management decisions (Vélez et al., 2024).

TGI has been found to be closely related to leaf chlorophyll content (Hunt et al., 2013), which makes it useful as an early indicator of problems with photosynthesizing material. Most previous work with TGI has been performed on agricultural crops (Xing et al., 2020; Lemes et al., 2022); however, it has been recognized for its applicability in forest applications (Gao et al., 2024). While perhaps less computationally intuitive compared to VARI, TGI also uses visible reflectance, making it another ideal index to use in high-resolution data acquisition such as

that obtained using drones. TGI response to stressors may be detectable before they become evident in other indices that use infrared reflectance data in their calculations. This may explain why TGI continued its downward trend while NDVI and VARI recovered from 2022-2023. Future endeavors should consider an annual time series assessment of TGI changes compared to measured chlorophyll concentrations. Deviations from known chlorophyll concentrations (McGregor & Kramer, 1963) throughout the year may be used to develop a risk index for some unforeseen disturbance agent.

While BSNB can lead to mortality in pine, it is primarily believed to impact future growth (Phelps et al., 1978). The trends observed in this study indicate that there is at least less photosynthetic capacity, and canopy coverage or depth exhibits an overall decrease. Using remotely-sensed data, particularly at a greater temporal and spatial resolution, would allow forest managers to identify subtle changes in canopy health and potentially mitigate the spread of the pathogen—via select tree removal, prescribed fire, etc. There is also some suggestion from the present study that indicates there may be a density component to the spread of BSNB in a stand, but more intensive study would be required to confirm this.

The present study has a shortcoming in that there is no historical or current inventory data to use for correlation with image indices. This occurred as a result of the late diagnosis of BSNB and the quick response to work to remove the trees. It is also worth a word of caution that as crown area decreases, the understory growth may confound expected decreases when assessing spectral indices over time (such as in 2022-2023; Gao et al., 2024). The indices used in this assessment are commonly used for disturbance detection and are, therefore, sensitive to disturbance from common agents such as insects or drought. In the forest assessed, there was no insect infestation (such as Ips or Southern Pine Beetle), drought did not precede or occur with index changes (<https://droughtmonitor.unl.edu/DmData/DataGraphs.aspx>), and BSNB was confirmed from needle samples from trees and litter using PCR analysis. The outbreak of BSNB in pine plantations throughout the southeastern United States caught most off guard, and scientists throughout the region mobilized to collaborate on determining the extent of BSNB, the impacts on growth and mortality in loblolly pines, and management implications to determine ways that potential impacts from this pathogen may be mitigated.

5. Conclusion

The indices selected are sensitive to changes in plant health and vigor and provide a method for tracking shifts in leaf light reflectance and chlorophyll content. The decreases in the index are consistent with observational changes, even though canopy area was not quantified as part of this study (which was undertaken retroactively to the onset of symptoms in the forest). The results indicate that growing-season changes are useful in detecting BSNB impacts, similar to other disturbance agents. Incorporating artificial intelligence and automation with time series analysis methods such as those performed in the present study may allow for con-

sistent monitoring of forested areas and provide forest managers with a way to get ahead of forest health risks before they become too widespread to manage.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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