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Fall River State Forest - Advanced Remote Sensing

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Project Title: Assessing Vegetation Restructuring and Wildfire Resilience in Freetown-Fall River State Forest: An Analysis of Prescribed Fire and Adaptive Management

Research Questions

1. Has the understory and overstory vegetation structure in Freetown-Fall River State Forest (FFRSF) changed since the Department of Conservation & Recreation (DCR) prescribed burning started over the last decade?
2. Have any other changes occurred in the Fall River State Forest vegetation due to other landscape management activities?
3. How has wildfire risk changed since the prescribed burning program began in 2009?

Research Objectives

This project will explore the viability of LiDAR data for detecting land cover change in the Freetown-Fall River State Forest resulting from the prescribed burning program. Changes in the understory vegetation and any other changes detected by LiDAR data will be analyzed using multitemporal change analysis.

Study Area

Freetown-Fall River State Forest (FFRSF) is a 6,596-acre reserve in southeastern Massachusetts. FFRSF consists of mixed deciduous and coniferous forests, hillocks, swamps, and a quarry, and is home to a 227-acre Wampanoag reservation. The land between Freetown and Fall River holds excellent historical and cultural significance for the Wampanoag Nation. The elevation spans from 42.2 to 248.2 feet above sea level. As of 2020, the site attracts 15,000 annual guests, who typically enjoy picnicking, hiking, fishing, and hunting activities. There are 18 known invasive plant species, making the ecosystem vulnerable to wildfires, as well as invasive, hardwood-defoliating insects such as the spongy moth, winter moth, and tent caterpillar, which have historically killed thousands of oak trees (Clark et al., 2022). Spongy moths typically hatch their eggs in late April to early May, while the eastern tent caterpillars usually hatch during mid-April to May (*Spongy Moths*. (n.d.). Mass Audubon. Spongy moth outbreaks occur every 5-10 years (Rindos, M. & Liebhold, A. M., 2023). Spongy moths create a research opportunity to find likely hotspots for these insects based on the presence of a high concentration of dead oak trees.

Timber is harvested in the Freetown-Fall River State Forest to promote ecosystem health, reduce wildfire risk, and support forest management (*Prescribed Fire | US Forest Service*, n.d.). Prescribed fires or burns happen in the Freetown-Fall River area and restore the health of the forest and its ecosystems (*Prescribed Fire | US Forest Service*, n.d.). These fires are facilitated by a team of experts who create a plan taking into account humidity, ideal temperatures, and wind conditions. Prescribed fires help prevent the spread of unnatural vegetation, protect watersheds, and encourage microbial activity (Gabbert, n.d.-b).

Overview of LiDAR

This study leverages Light Detection and Ranging technology to accurately determine individual tree height and overall canopy cover. LiDAR missions are typically flown on planes or unmanned aerial vehicles. The technology works by emitting laser light pulses from the primary sensor. The pulse hits various surfaces, including vegetation, on its way to the ground and back. Distance and height are calculated based on the time it takes for the light to be emitted from the sensor and return to the instrument. A short return time indicates taller height, while a longer return time indicates shorter height. The data product returned from LiDAR missions usually consists of a point cloud, in which millions of points are aggregated into a collection that can three-dimensionally represent objects based on their response to the emitted light. Based on certain heights, points can be classified to define features, including buildings, various levels of vegetation, and the ground.

Data Description

Refer to Table 1 for a list of each data source.

Our LiDAR dataset was retrieved from the two most recent USGS LiDAR missions - 2011 and 2021. Differences in the resolution existed between the two datasets and had to be considered. With the estimated point spacing of 0.2 meters, the 2021 dataset is much higher in resolution compared to the 2011 dataset at 1 meter. The point spacing represents the overall density of the point cloud, in which a smaller point spacing represents a higher resolution and the potential of more detailed results. Analysis of prescribed burn areas and logged areas would not be possible without the contribution of the prescribed area and logged area polygons provided by Paul Gregory of the DCR. These shapefiles consist of records of area burned since 2009 and logged areas since 2004. Vegetation cover was collected using LANDSAT 5 and LANDSAT 8, obtained through Google Earth Engine.

Methods

Lidar

Lidar data from 2011 and 2021 were acquired using NOAA's Data Viewer. ArcGIS Pro was then used to process both datasets to determine, in sequence, ground height, canopy height, and canopy cover. First, we downloaded the Lidar data from NOAA using the specifications shown in Figure 12. We combined the individual lidar tiles using the Create LAS Dataset tool in ArcGIS Pro. The LAS to Raster tool was used twice—first filtering for ground points and then for all points—to generate a ground layer and a surface layer, respectively. We used Raster Calculator to subtract the ground layer from the surface layer to derive canopy height. Next, we applied the Reclassify tool to generate binary ground and canopy layers, where values under 1.8 meters (6 feet) were classified as ground, and all other values as canopy. This methodology was applied identically to both the 2011 and 2021 datasets.

Following this, we imported the binary classification layers into the newly open-access software TerrSet, where we performed a Crosstab analysis. Crosstab provides a pixel-by-pixel comparison between the two layers, identifying where values remain consistent, where they differ, and the nature of any change. This allowed us to detect areas where the canopy remained stable, expanded, or was removed.

NDVI

Google Earth Engine was used to find vegetation cover. Images were obtained from Landsat 8 for the 2021 and 2024 periods, and from Landsat 5 for the 2003 and 2011 periods. Each image had less than 10 % cloud cover and was taken between May and August to ensure full vegetation to depict the vegetated cover accurately. Images were exported from Google Earth Engine as a .tif file to Google Drive, downloaded to the computer, and then imported into ArcPro for further manipulation. Once in ArcPro, the image was clipped to the study, and the tool Raster Calculator was used to depict a change between 2011- 2021 and 2021-2024 for the burn areas and 2003-2011 for the harvested areas. The symbology was changed from stretch to classify. NDVI ranges from -1 to 1, signifying 100% loss in vegetation and 100% gain in vegetation. In this dataset, there were no such extremes. This dataset had five classes: moderate loss (≤ -0.10), slight loss (≤ -0.03), no change (≤ 0.03), slight gain (≤ 0.10), and moderate gain (≥ 0.10).

Results

Alongside the LiDAR data, the Normalized Difference Vegetation Index (NDVI) was used to compare the results with the LiDAR results. Changes in vegetation were taken from 2011-2021 to match the period the LiDAR data was taken, and 2021-2024 to see if further change had occurred.

Within the burn boundaries, between 2011 and 2021, vegetation mostly had a slight gain or no change (Figure 5). However, within the same study area from 2021 to 2024, there was no change, but a slight loss in vegetation area (Figure 5). In the areas with moderate loss in 2011-2021, there was significant regrowth in 2024 (Figure 5). Focusing on the northwestern portion of the study area, an area thoroughly looked at using LiDAR, it is clear that there was no light gain or change between 2011 and 2021. There is little to no story of loss due to prescribed burnings and no sign of the burning courier spotted using LiDAR (Figure 6). There was more loss in vegetation from 2021 to 2024 compared to 2011-2024 (Figure 6). Moving to the southeastern region of the study area, there is moderate loss in a large portion of the burn area from 2011 to 2021, likely due to a recent prescribed burn at the time of the imagery (Figure 7). In that same area, there is a moderate gain in vegetation from 2024 to 2021 (Figure 7). Moving on, in the area where timber was harvested, there was minimal change in vegetation, with the majority of the study area being categorized as slight gain, no change, or slight loss in canopy in 2011-2003 (Figure 8). Most of the northern portion of this study area had a slight loss of vegetation, while in the southern central portion of the study area, there was a majority of no change (Figure 8).

Conclusion

Our findings show that NDVI and LiDAR are most effective for forest management analysis. NDVI offers more temporal flexibility due to its frequent data availability, allowing it to capture more recent burns. For example, Figure 11 compares vegetation loss between NDVI and LiDAR from 2011 to 2021. Since the LiDAR data was collected in April 2021 and the prescribed burns occurred in June 2021, LiDAR could not detect these later burn events. However, LiDAR excels at identifying small-scale changes that NDVI may miss due to its coarser spatial resolution. As shown in Figure 10, the narrow burn corridors established by the DCR along the edges of the burn polygons are visible in the LiDAR data but are not captured in the NDVI analysis.

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We thank Paul Gregory of the Department of Conservation and Recreation for supporting our study and providing essential information to make this research possible. Additionally, thank John Rogan and Fatemeh Kordi for their unwavering support and dedication to Clark University and its students.

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Tables and Figures:

Table 1: Data Table

Name	Source	Type
[Lidar Data 1] (2021)	https://apps.nationalmap.gov/lidar-explorer/#/	LAS point cloud
[Lidar Data 2] (2015)	https://apps.nationalmap.gov/lidar-explorer/#/	LAS point cloud
LANDSAT 5 Imagery (2003)	Google Earth Engine: LANDSAT/LT05/C02/T1_TOA	Satellite imagery
LANDSAT 5 Imagery (2011)	Google Earth Engine: LANDSAT/LT05/C02/T1_TOA	Satellite imagery
LANDSAT 8 Imagery (2021)	Google Earth Engine: LANDSAT/LT08/C02/T1_TOA	Satellite imagery
LANDSAT 8 Imagery (2024)	Google Earth Engine: LANDSAT/LT08/C02/T1_TOA	Satellite imagery
Freetown-Fall River State Forest Boundary Shapefile	MassGIS	Shapefile (polygon)
2016 Land Cover/Land Use	MassGIS	Shapefile (polygon)
Freetown-Fall River State Forest / Wampanoag Native American Reservation	OpenStreetMap MassGIS Shapefiles	Shapefile (polygon)

Table 2: Depicting the dates that each image (both LANDSAT and LiDAR) was taken in comparison to the prescribed burnings

Type	Date
LANDSAT 5 Imagery (2003)	July 16, 2003
LANDSAT 5 Imagery (2011)	July 26, 2011
LANDSAT 8 Imagery (2021)	July 27, 2021
LANDSAT 8 Imagery (2024)	June 1, 2024

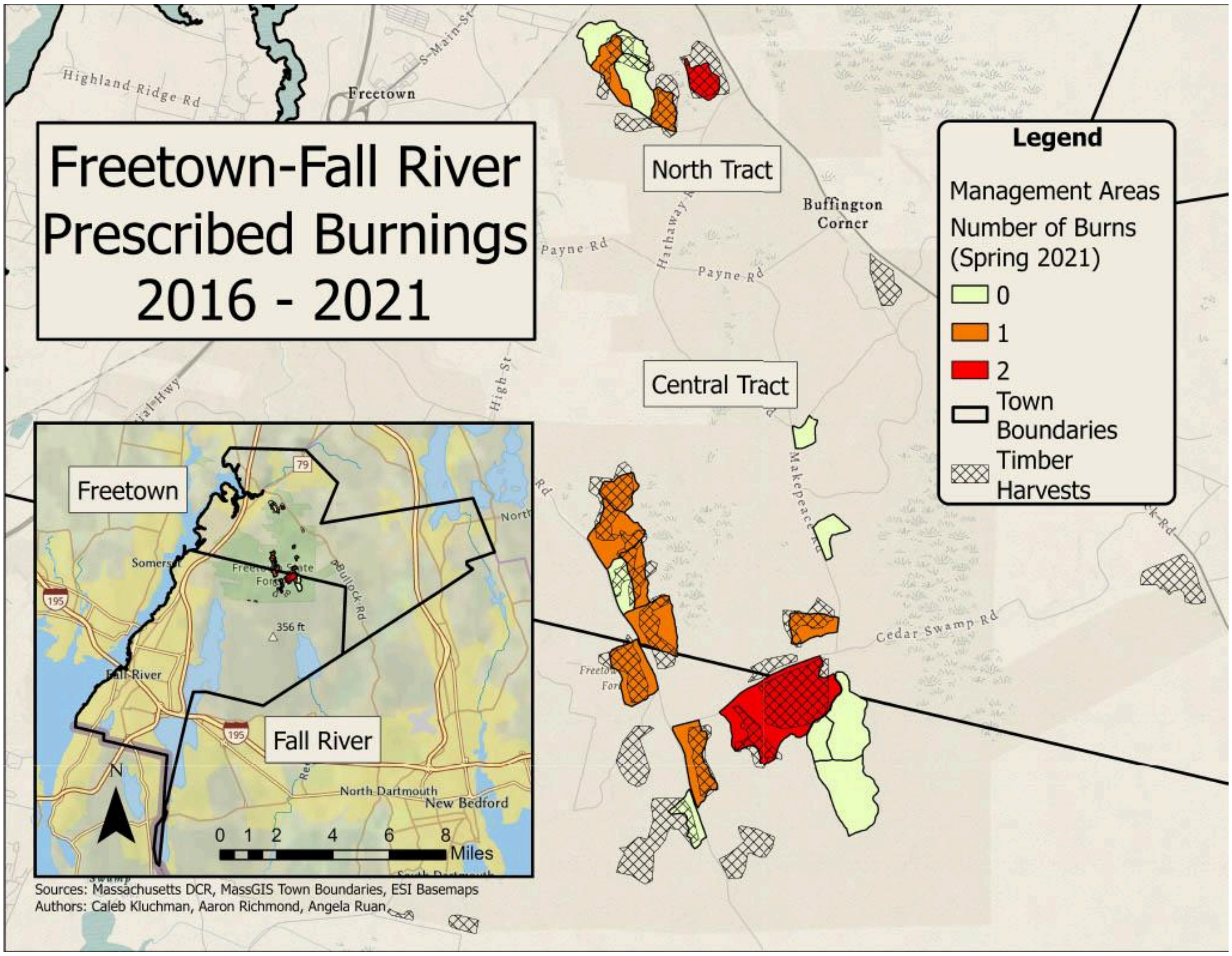
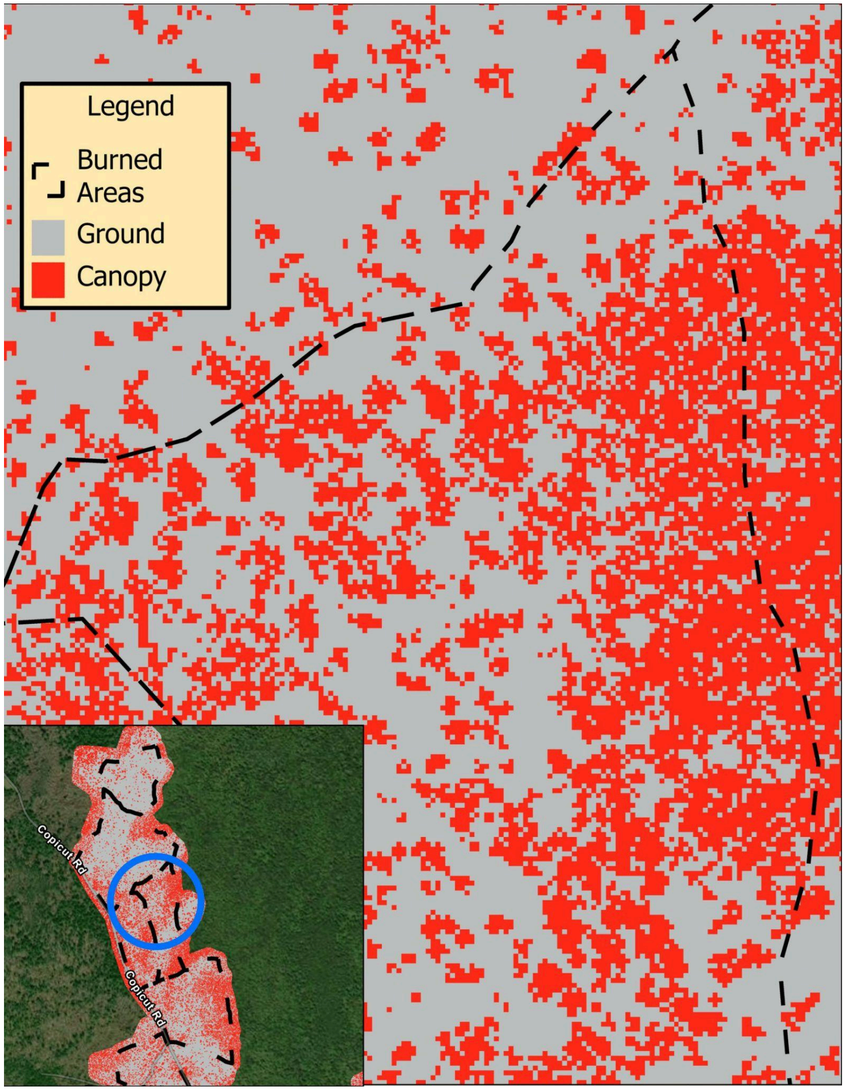


Figure 1: Study Area Map of Freetown-Fall River Prescribed Burnings (2016-2021)

Figure 2: Canopy Height Maps [LAS Dataset to Raster] Left: 2011 canopy cover, Right: 2021 canopy cover. Burns occur April 12, 2019, and September 22, 2022.


Legend
Burned Areas
Ground
Canopy
Copicut Rd
Copicut Rd

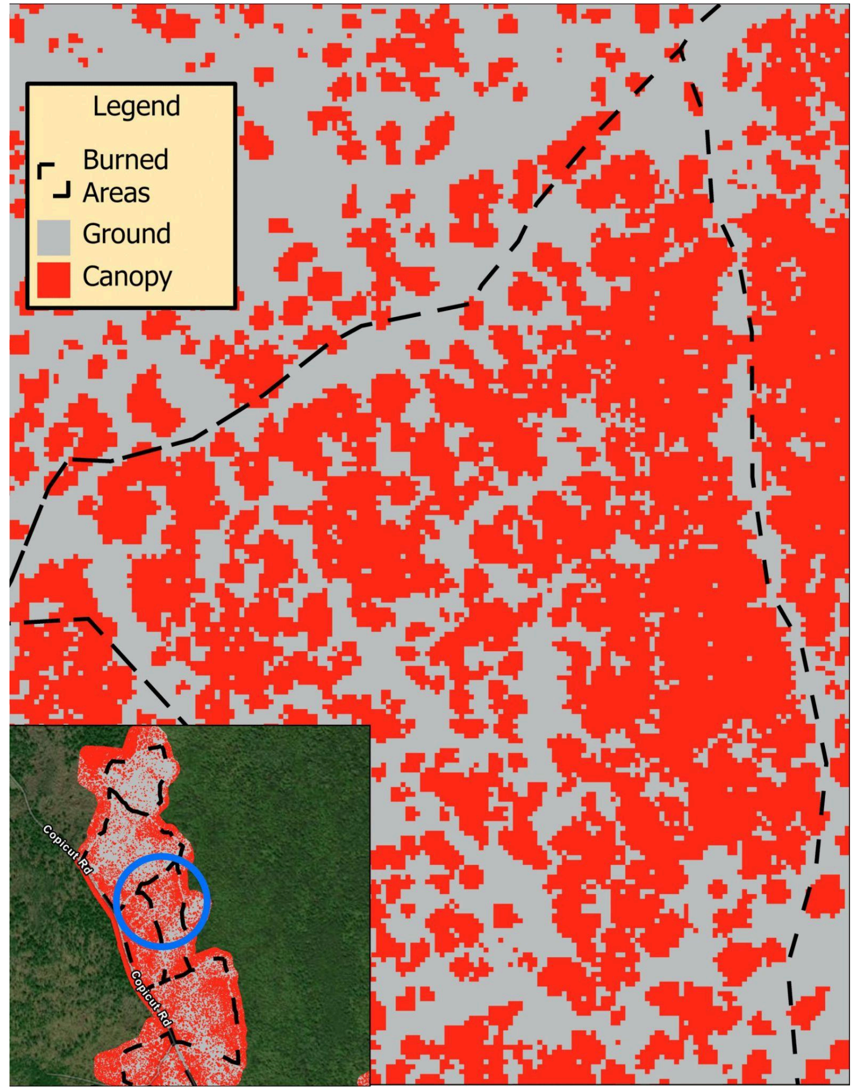

Legend
Burned Areas
Ground
Canopy
Copicut Rd
Copicut Rd

Figure 3: Canopy Height Maps [Reclassify] Left: 2011 canopy cover, Right: 2021 canopy cover. Burns occur April 12, 2019, and September 22, 2022.

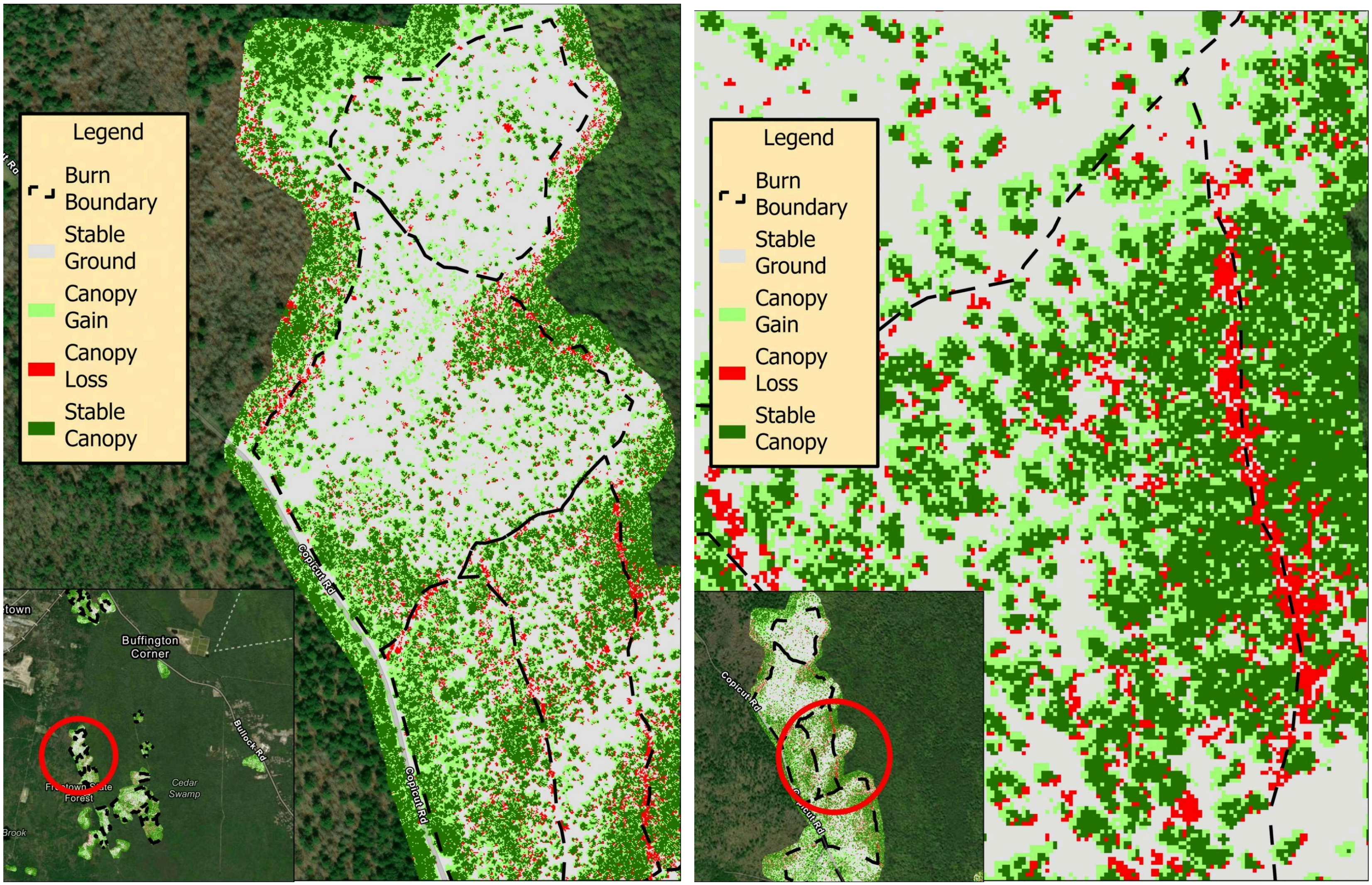


Figure 4: Left: change, Right: Zoomed-in image. Zoomed-in image burned: Burns occurred on April 12, 2019, and September 22, 2022.

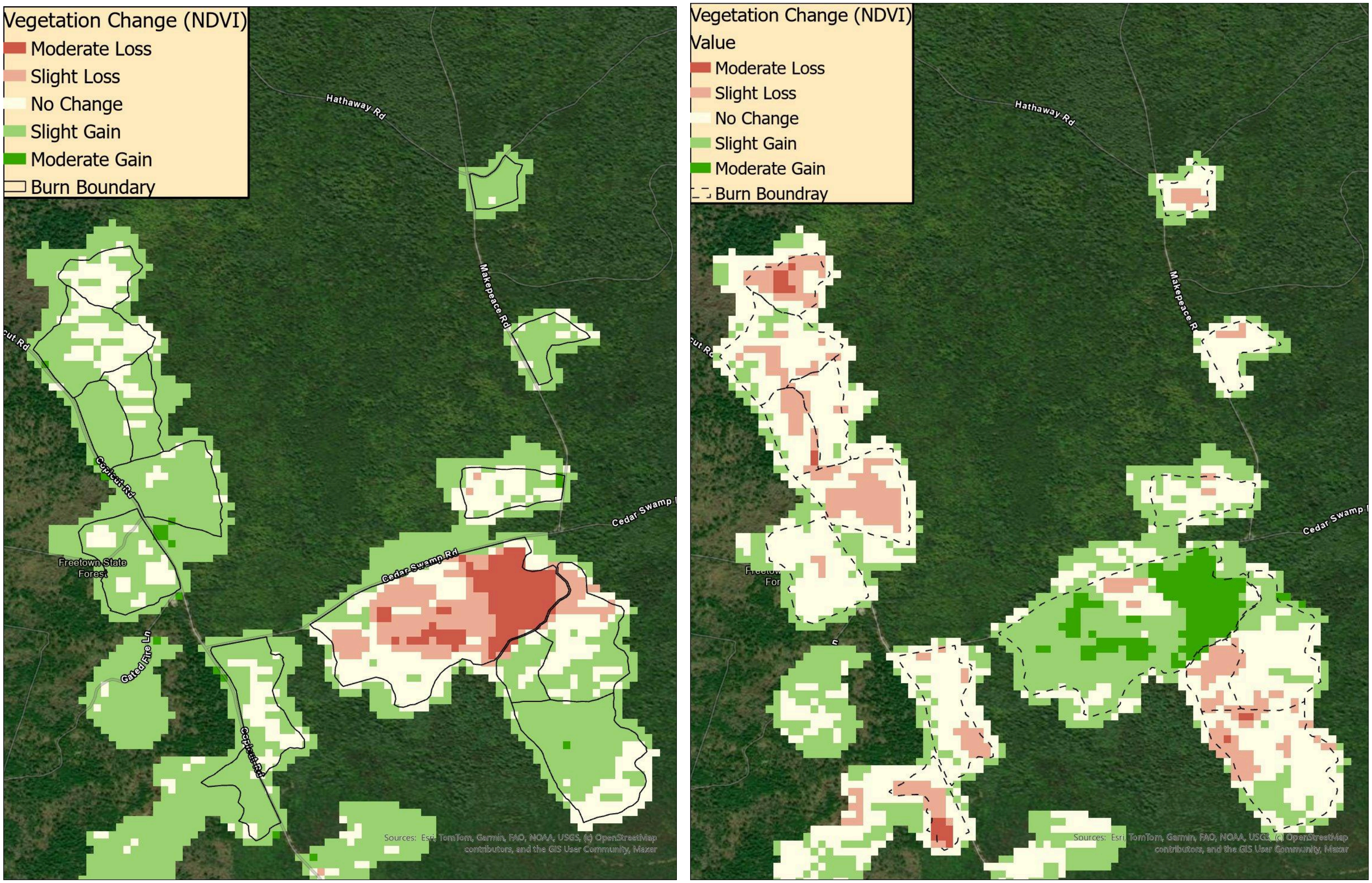


Figure 5: Vegetation Change for Burned Boundary Left: 2011-2021, Right: 2021-2024

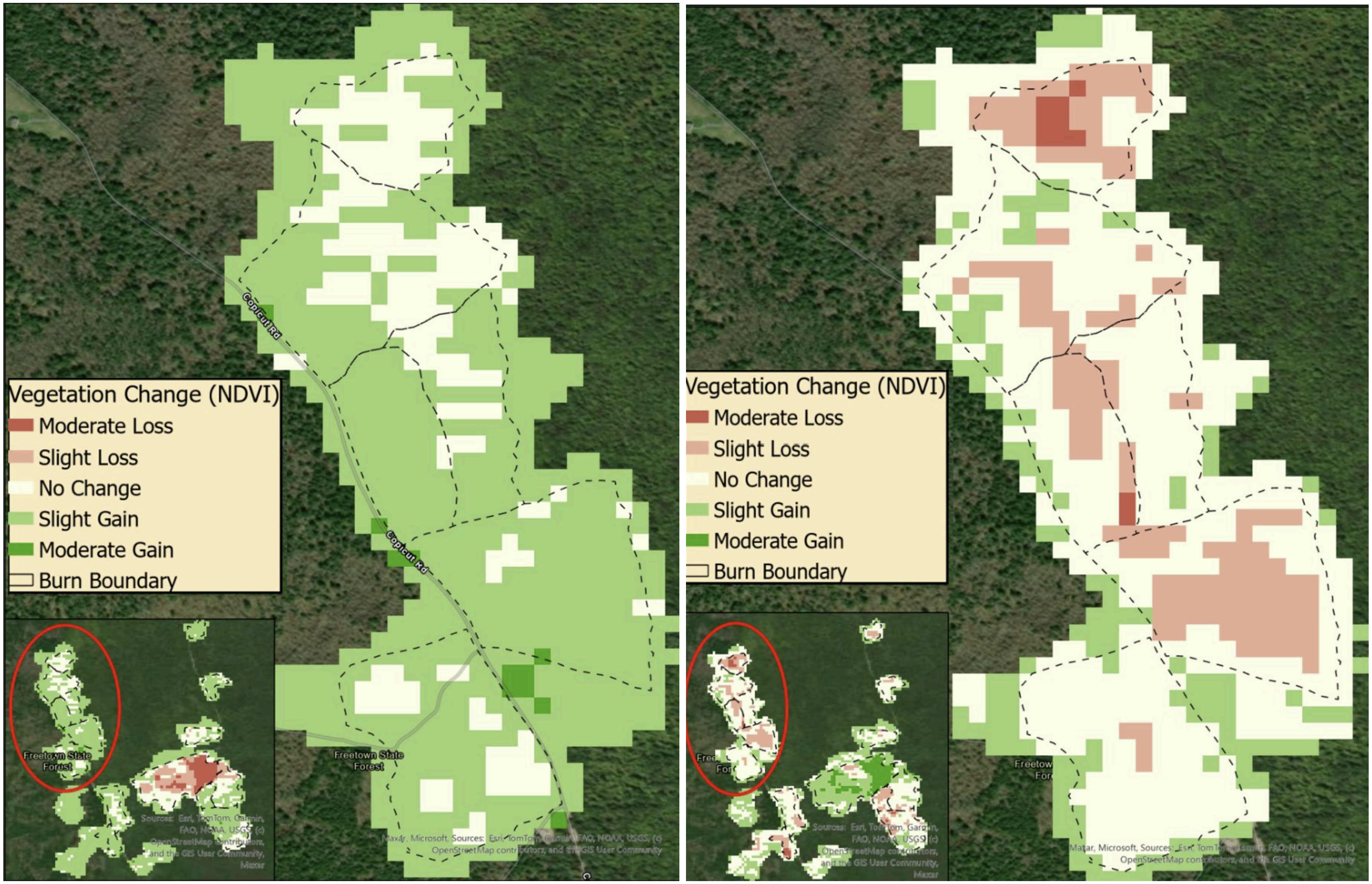


Figure 6: Vegetation Change for Burned Boundary in the Northwest region of the study area, Left: 2011-2021, Right: 2021-2024.Burns occurred on March 28, April 2, April 12, May 8, 2019, April 25, October 22, 2022, March 22, October 27, 2023.

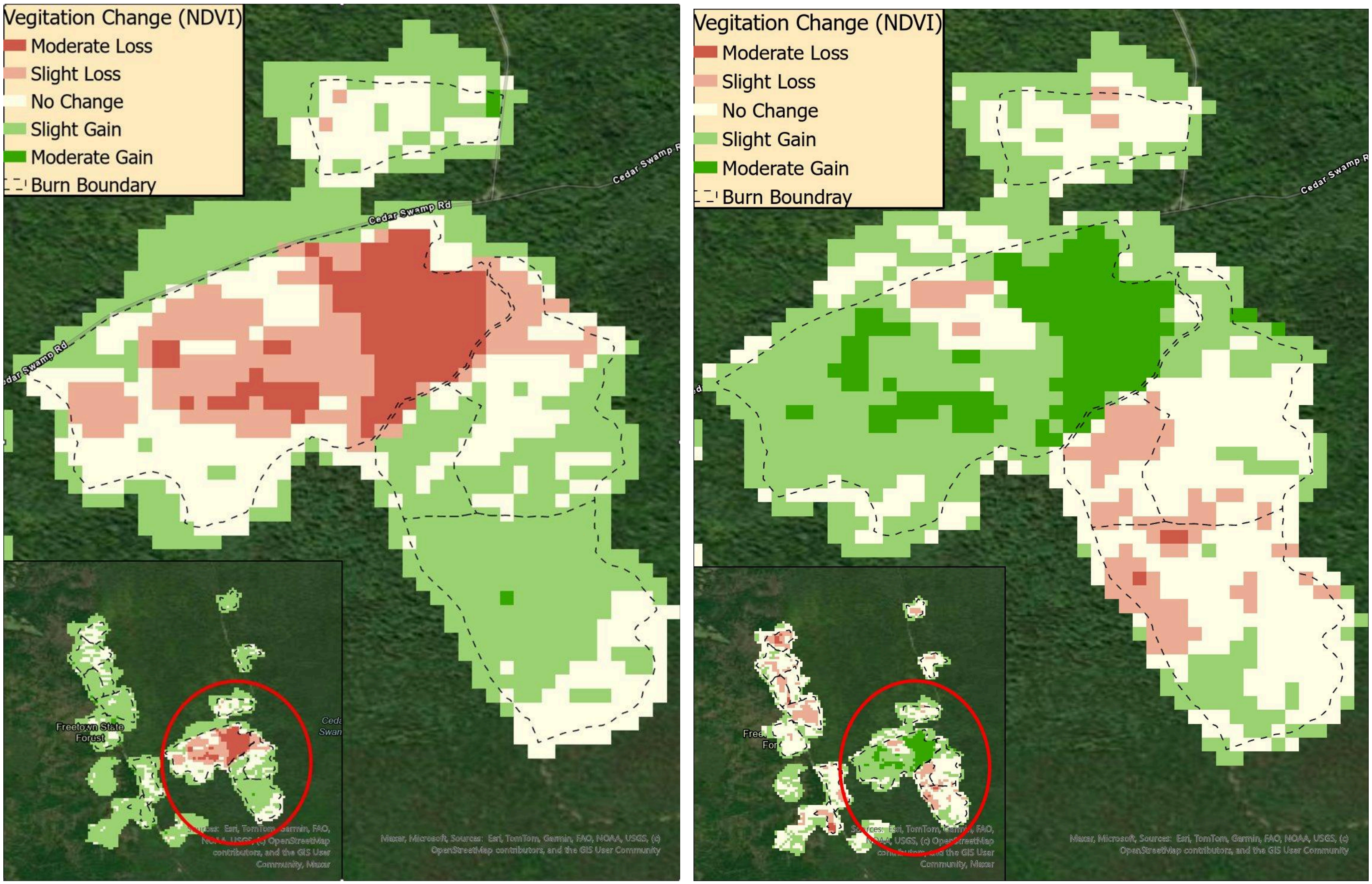


Figure 7: Vegetation Change for Burned Boundary in the Southeast region of the study area, Left: 2011-2021, Right: 2021-2024. Burns occurred August 3, 2019, April 6,7, June 18, 2021, April 28, 2023, and October 28, 2023.

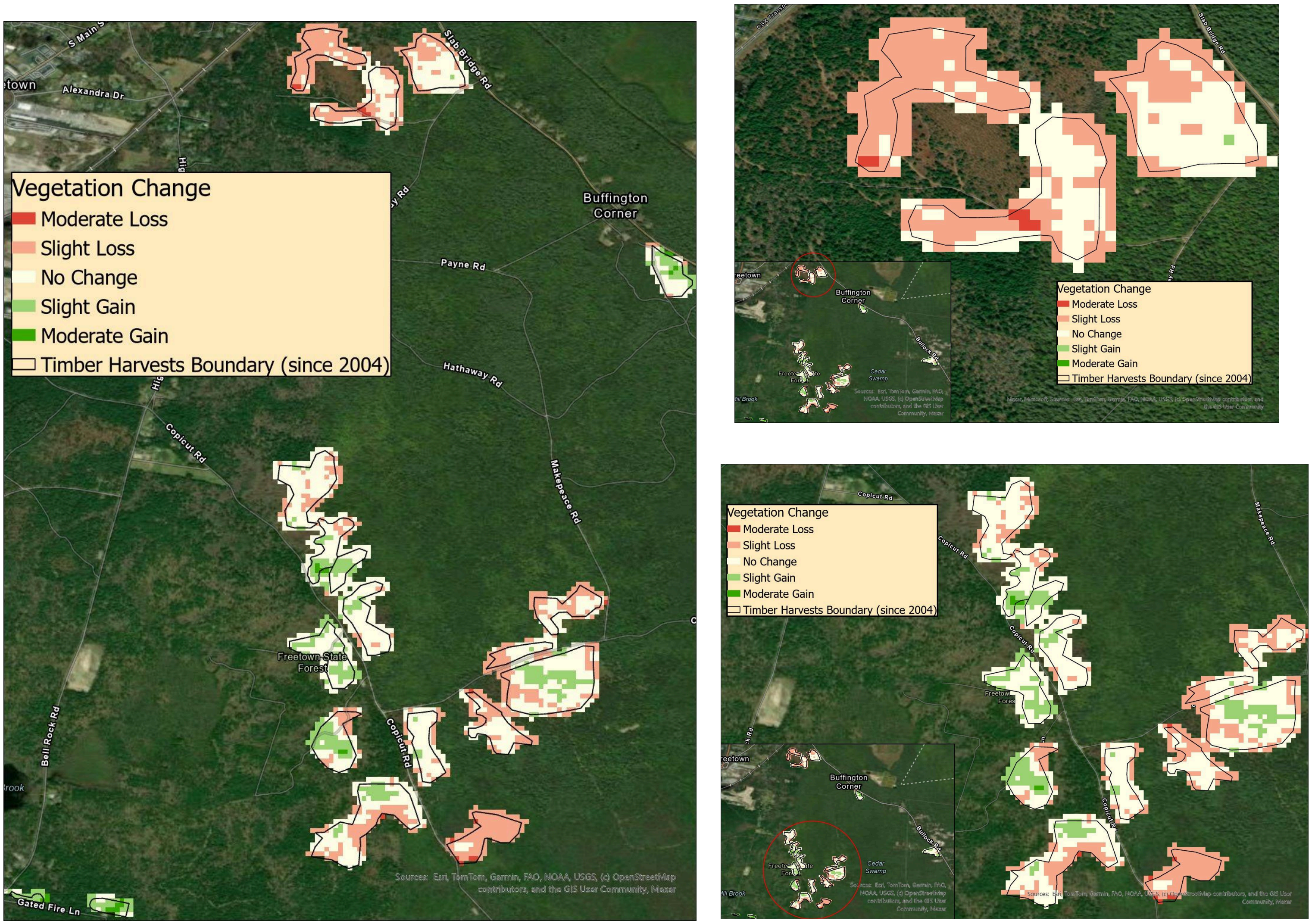


Figure 8: Vegetation Change 2003-2011 for Timber Harvest Boundary, Left: Entire study area, Right-top: Northern portion of the study area, Right-bottom: Southern/Central portion of the study area

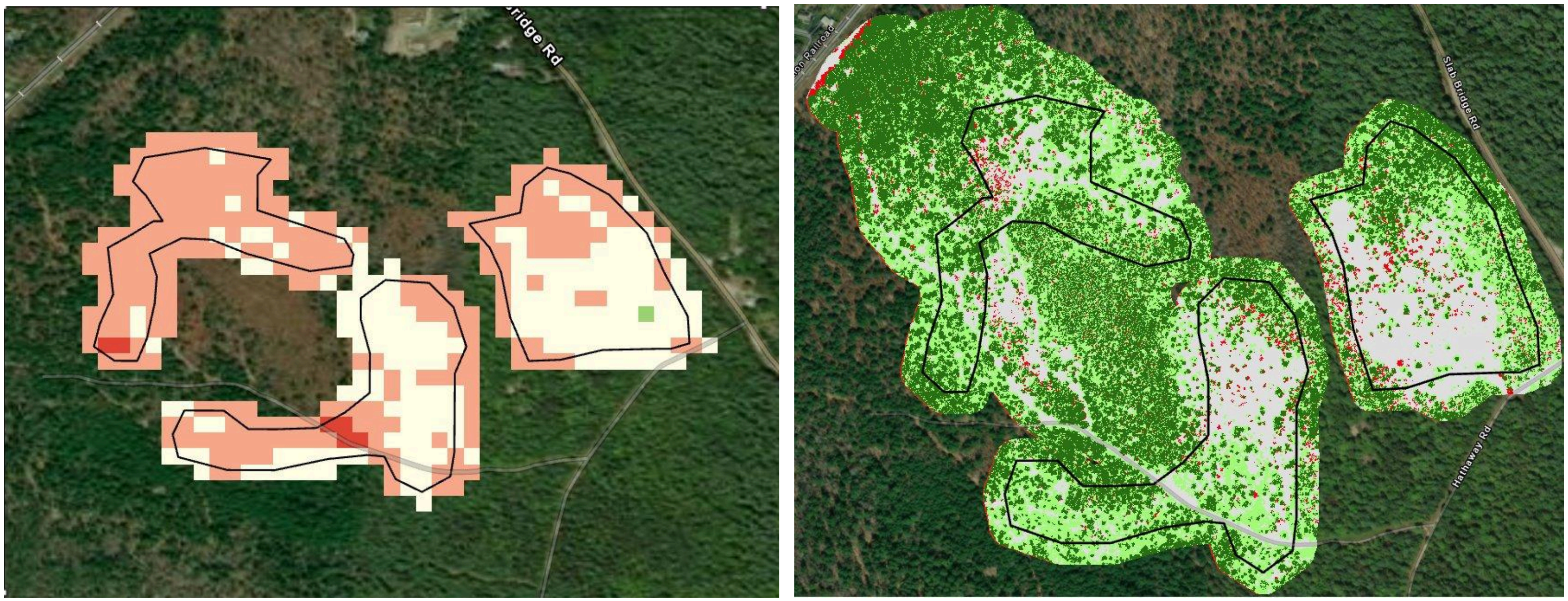


Figure 9: Comparing change analysis methods within the logged area, Left: NDVI 2003-2011, Right: LiDAR 2011-2021. Logging occurred in 2007.

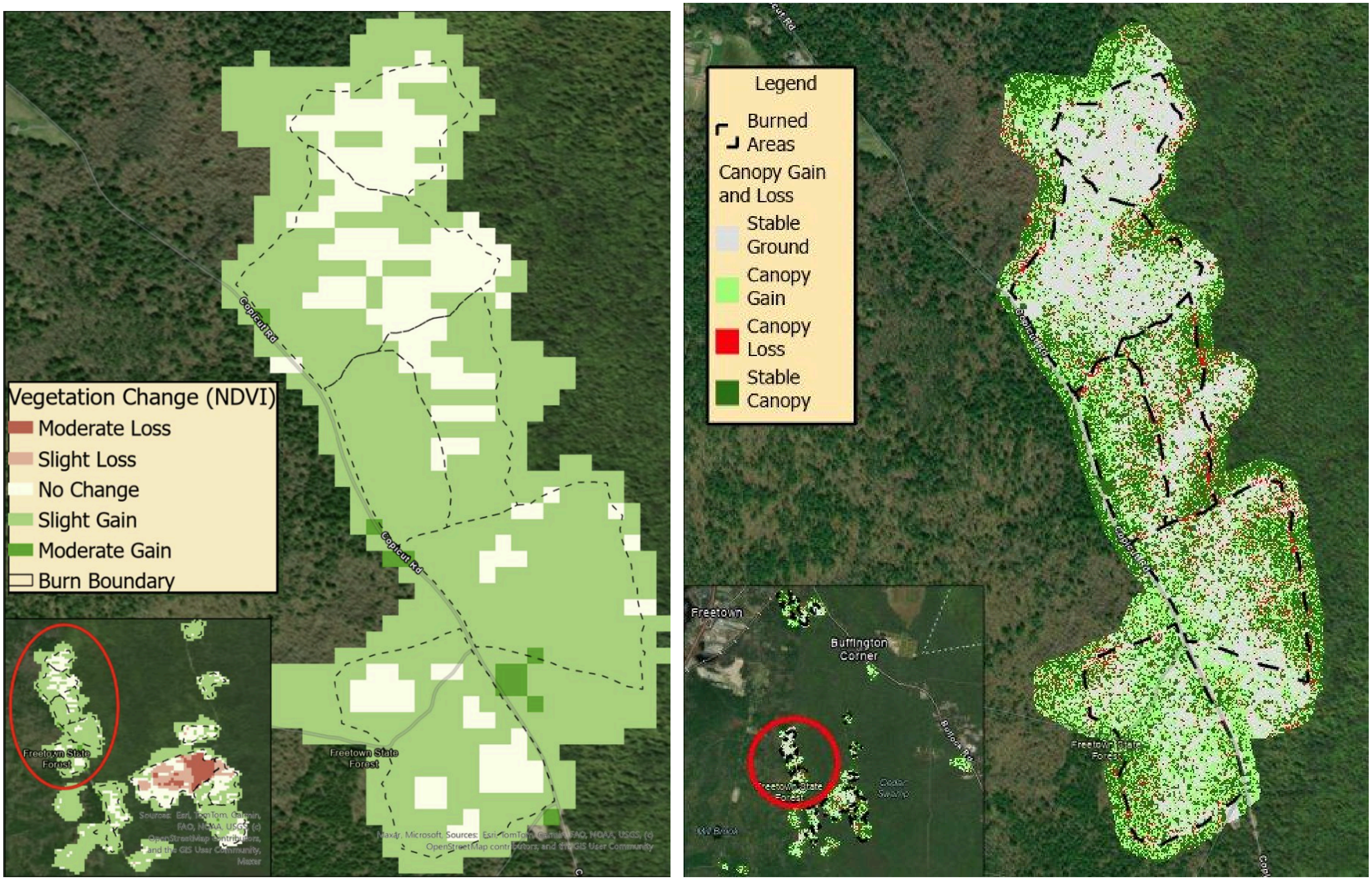


Figure 10: Comparing change analysis methods within the northwestern part of the burned area. Left: NDVI 2011-2021. Right: LiDAR 2011-2021

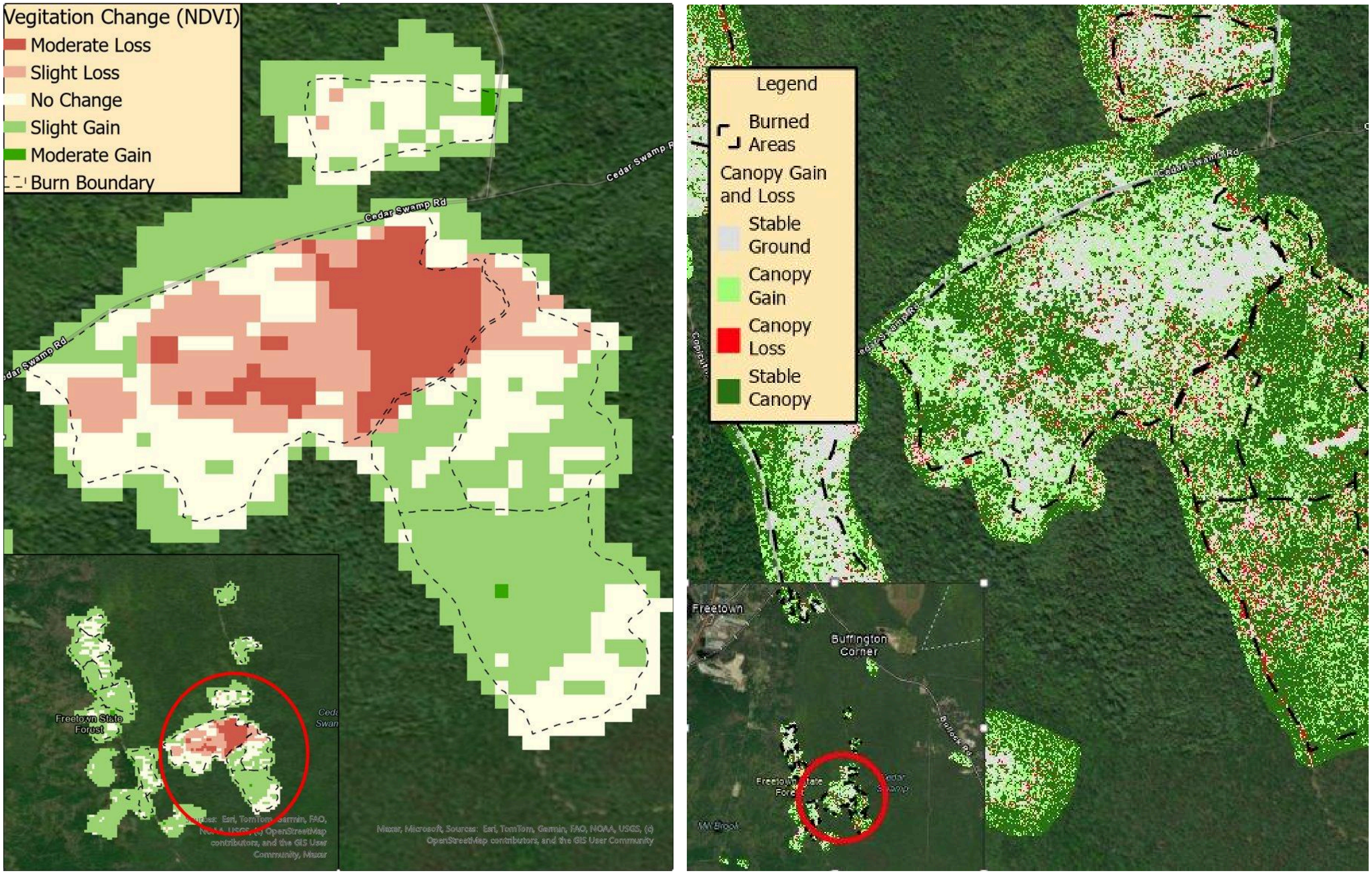
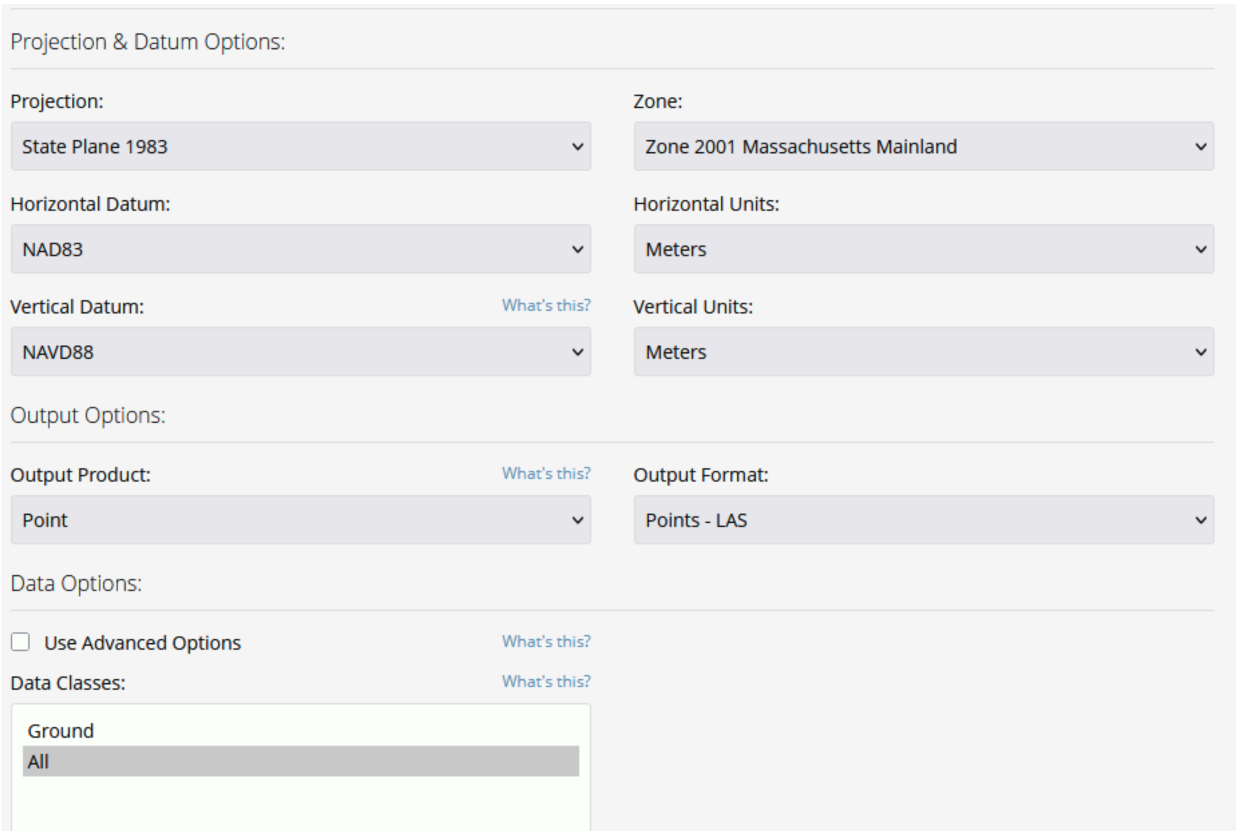


Figure 11: Comparing change analysis methods within the Southeast region of the study area, Left: NDVI 2011-2021, Right: LiDAR 2011-2021

Figure 12: LIDAR Data Specifications for NOAA: Data Access Viewer



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