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Forest Ecosystem Monitoring Cooperative
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**FEMC FINAL REPORT**

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**Project Title:** Training a Change Detection Algorithm for US Northeast Forests

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**Executive Summary**

The need for reliable landscape monitoring tools is growing rapidly with the advent of climate goals that rely on forests as natural climate solutions. However, none of the leading monitoring tools were developed for the forest types and disturbance regimes of the Northern Forest region. Our initial ground-truthing analysis of three of the most commonly used satellite-based disturbance detection algorithms found that they underperformed in detecting the smaller-scale, uneven-aged harvests and natural disturbances that are most prevalent in our region. To address this problem, our objective was to train a forest change detective using the Landtrendr on Google Earth Engine (LT-GEE) platform, which we found was the best performer, by far, yet with ample room for improvement. To this end, we carried out an iterative 'tuning' process to improve overall LT-GEE performance, which was evaluated against three sources of 'ground-truthing' data: landowner harvest records/maps, visual image verification software (TimeSync) and field reconnaissance.

Overall, we achieved substantial gains in overall LT-GEE performance for change detection in Northern Forest landscapes, especially for harvest-related disturbances, relative to the default LT-GEE configuration. Our tuning yielded several LT-GEE 'versions' helpful for regional use, intuitive comparisons of their strengths and limitations, and a practical understanding of key parameters that shape LT-GEE outputs. As a project deliverable, much of this learning was summarized in an unofficial 'user's guide' to support future LT-GEE applications in the Northern Forest region (https://cafri-labs.github.io/lt_resources/). These online resources include R code for evaluating LT-GEE output maps against reference geodata, providing an efficient and consistent basis for cross-validation in future tuning efforts. Next, based on the best LT-GEE tunings among those tested, we generated sets of historical disturbance maps for the entire FEMC coverage area (NY, MA, CT, RI, VT, NH, ME) at 30m annual resolution, in effect reconstructing the disturbance history of the region's forests back to 1990. These data products and their metadata are archived with FEMC. Broadly this project has taken the first essential steps in applying the LT-GEE change detection platform for landscape monitoring, in support of forest science and stewardship across the US Northeast.

## Background & Rationale

Landscape scale forest monitoring tools are an essential part of the process to growing and sustaining forests as a natural climate solution (1). Several states in the FEMC region are moving forward with wide-reaching climate legislation that include aggressive emissions reduction targets that rely heavily on forest carbon sinks as emissions offsets, which in turn heightens the pressure for landowners to conserve lands and sequester more carbon. Market-driven and regulatory mechanisms to achieve these outcomes, much like forest certification programs (e.g., FSC, SFI) require some basis for monitoring and verification to ensure landowner compliance over time. In addition, forest disturbance regimes in the FEMC region are expected to continue to shift and intensify due to insect pest outbreaks and extreme weather events (2), highlighting the need for monitoring tools that can differentiate harvesting from other causes of disturbance. As a result, there is an urgent need for efficient and accurate monitoring tools that can provide timely and actionable information on how and where disturbance is taking place, both to understand its effects on forest ecosystem structure, functions and services (including climate benefits) and to inform stewardship actions in response.

Remote monitoring serves multiple purposes and has multiple benefits for both public and private stakeholders in the FEMC region. Accurate remote monitoring allows landowners and managers to better understand the changes that are happening on their own land and supports more efficient and timely ground verification (3). Regionally specific monitoring tools can also be deployed as an alternative to other costly or controversial monitoring tools such as randomized site visits or harvest notification programs. Secondly, it provides landowners greater confidence in monitoring protocols implemented by easement or offset owners, preventing landowners from being unfairly penalized for harvests that did not occur. This is especially important as forest pests/pathogens and extreme weather are having an increasing impact on forested lands (2).

Existing satellite image-based forest change detection algorithms have great potential to be implemented to efficiently track and quantify forest disturbances related to natural processes and human activities, such as management, as well as land use changes (3). However, the leading algorithms underlying such monitoring tools were not developed nor had they been 'trained' with the FEMC region's forests and disturbance regimes in mind (3-6). Our recent ground-truthing on 43,000 hectares of working forests in the Adirondacks (NY) found that the three most commonly used satellite-based forest change detection algorithms were unsatisfactory for monitoring purposes in this region (7). These algorithms performed best at detecting clearcut harvests, which are relatively rare in most of FEMC's region, while they overall did poorly in detecting the more commonly used partial harvests and uneven-aged silvicultural systems. However, we did determine that the Landtrendr algorithm implemented in the open-source Google Earth Engine platform (LT-GEE) was the most accurate of the three and offered the most promising avenue for further tuning and monitoring applications across the mixed forest landscapes of the US Northeast.

## Goal & Supporting Objectives

Our goal was to develop a version of the LT-GEE algorithm trained specifically for the forest types and disturbance regimes of the FEMC region, that is, the US Northeast. Training this tool relied on existing data-sharing partnerships with working forest landowners, the unique patchwork of private and public forest land in the Adirondacks (NY) region, and the open-source LT-GEE implementation that allows us to carry out algorithm tuning and testing (8). We used an iterative 'tuning' process to calibrate LT-GEE operating parameters to find one or more algorithm configurations that yielded more accurate outputs, based on multiple ground-reference data sources. Additional objectives included sharing the best Northern Forest-tuned version(s) of the LT-GEE change detection tool that we identified; generating maps of forest disturbance history (back to 1990) across the NF region; and sharing these maps of disturbance history freely with scientists, practitioners and stakeholders across the region via the FEMC website and data archives.

This project directly addressed the FEMC priority areas of *Forest Pests and Disturbance Regimes* and *Forest Inventory and Relationship to Carbon and Management*. The outputs from this project support the goals of three priority topics of interest: 1) identifying patterns and nature of tree mortality following recent acute disturbance events, 2) improving data sources and/or extending the historical record of disturbances in FEMC's Disturbance Monitoring Program, and 3) integrating regionally specific remote sensing-based tools to detect and monitor forest clearing, forest conversion, land use change and/or forest health.

**Approach**

We 'tuned' or calibrated the LT-GEE algorithm for Adirondack forests using an iterative process involving multiple types of reference data, including landowner harvest records, image-based verification and extensive field reconnaissance.

The goal of our tuning process was to, as closely as possible, align algorithm outputs with real-world conditions, i.e., the known timing and spatial location of disturbance events. For this reason, we relied primarily on management records (including harvest location, timing, type, removals by species/grade) provided to CAFRI by industrial forest landowner partners. In fact, this project would not have been possible without the generosity of Lyme Adirondack Forest Co., F&W Forestry, Timberlink/ATP, and ESF Forest Properties staff, who shared detailed harvest records and maps covering the last few decades. This reference data covered over 375,000 acres of working forest land and was essential for 'tuning' purposes, i.e., comparing the performance of LT-GEE under different algorithm configurations to identify the best options.

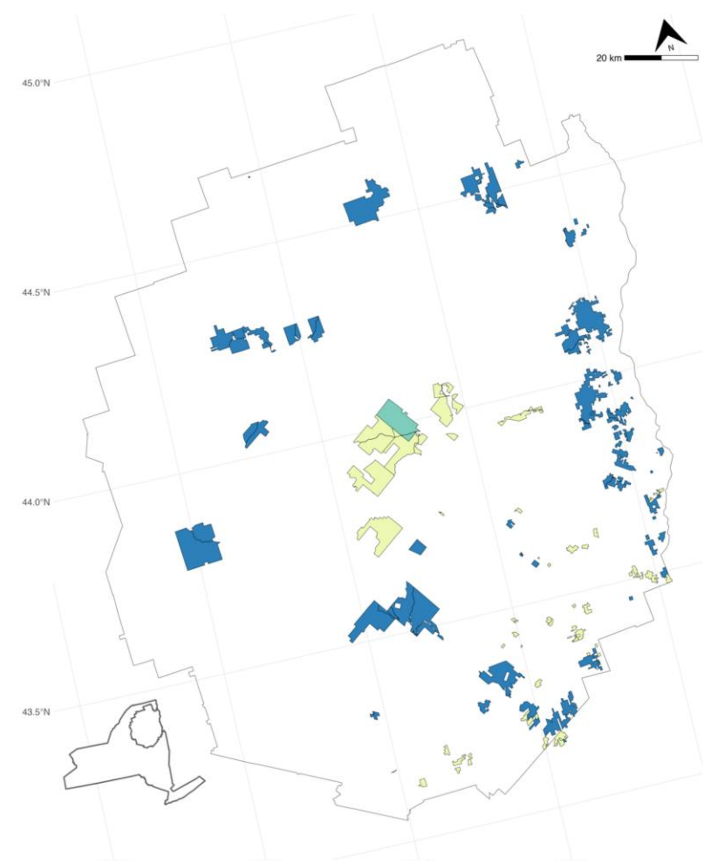


***Figure 1****. Extent of Adirondack working forest lands for which we had detailed harvest records and maps for LT-GEE tuning and validation purposes.*

The LT-GEE algorithm is a temporal segmentation algorithm that uses surface reflectance values from Landsat imagery to construct reflectance trajectories, select vertices or 'break points' and to them classify those 'breaks' as disturbance events. The LT-GEE algorithm can be iteratively tuned using the 15 parameters built into the GEE interface. There are two set of parameters available for tuning by users. The first set of parameters controls how the algorithm constructs and selects segments. These parameters make the algorithm more or less sensitive to individual disturbance events at the pixel level. The second set of algorithm parameters affects the construction of map outputs. These parameters control which detected disturbances are included in the map output by setting bounds for pixel characteristics like initial reflectance, length of disturbance and minimum disturbance size. The goal of this tuning process was to identify the combination of algorithm parameters that best balanced sensitivity (minimizing false negatives) and specificity (minimizing false positives).

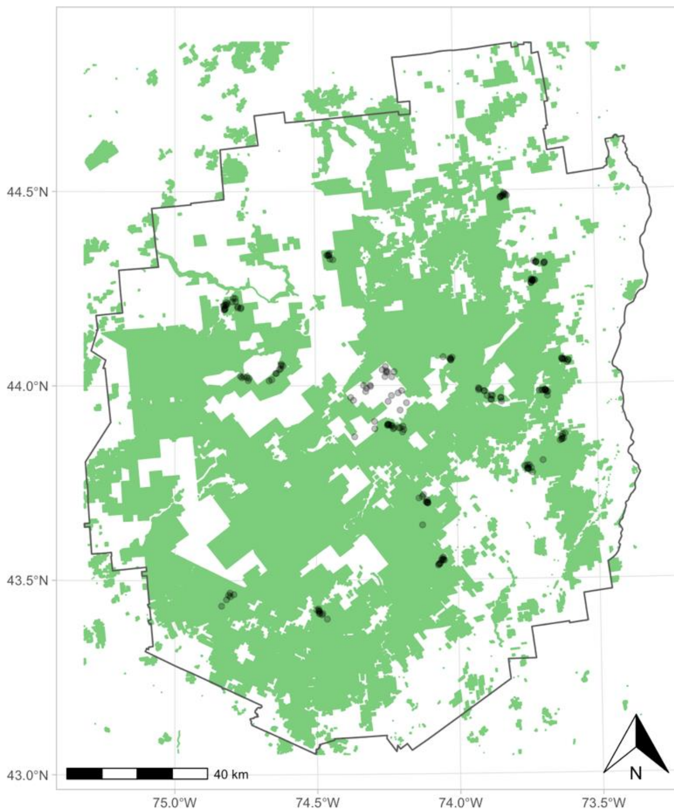


***Figure 2***. *Locations of field ground-truthing sites in the Adirondack Mountains, NY. Green areas represent NYS Forest Preserve lands.*

To assess performance of different LT-GEE 'tunings' (or algorithm configurations), we followed a two-stage ground-truthing process that used image-based and field-based (in situ) observations. Stage one involved a manual 'expert' verification using the LT-GEE companion tool TimeSync (9), which is based on satellite and aerial orthoimagery. This image-based tool is commonly used for validating outputs of change detection tools, due to the very limited availability (if any) of comprehensive field-based data sets (of disturbance timing and location). The second stage involved an extensive field campaign to ground-verify a stratified sample of pixels (i.e., disturbance patches) where LT-GEE detected change outside of known harvest units, primarily on the NYS Forest Preserve (where harvesting is prohibited). During July-August 2022, a field crew of ESF graduate students covered more than 220 trail and backcountry miles over 23 days of field work, surveying 188 sample points at a total of 25 sampling locations (disturbance patches). By focusing field sampling in areas of reserve (unmanaged) forests that LT-GEE had identified as disturbed since 1990, we were able to estimate commission error (false positives) for natural disturbance detection in our study area. Altogether, ground-truthing results informed selection of regional 'tunings' of LT-GEE that were sensitive to both natural disturbances and harvesting practices of the FEMC region.

After selecting LT-GEE tuning(s) that yielded the most improvement in overall accuracy relative to default settings, we implemented these algorithm configurations at a regional scale to generate maps of disturbance history for the entire FEMC service area (NY, MA, RI, CT, VT, NH, ME). The tunings themselves, i.e., the parameter sets and options used to configure LT-GEE for a specific set of outputs, are also useful products for future applications, including further tuning based on expanded and/or locally-relevant reference datasets. Tuning results and suggestions for future work were included in a 'Lessons & Resources' guide that we developed for regional users new to LT-GEE.

**Project Deliverables**

1. **One or more LT-GEE 'tunings' (algorithm configurations) for improved change detection in US Northeast forests, with instructions for open-access use on GEE platform.**

Tuning Landtrendr on Google Earth Engine (LT-GEE) involved testing parameters individually and in multiple combinations, to identify the parameter space (if any) in which algorithm performance (e.g., harvest detection) was significantly improved over default values. A total of 28 unique parameter sets were tested and several options were identified as providing the most net improvement overall. Testing was done through iterative calibration and validation against forest harvest records/maps provided by industrial forest landowners covering an extent of over 375,000 acres of the Adirondacks, as well as image-based and field-based validation efforts, as outlined above. Details of the tuning effort, including all parameter sets tested and those selected as 'best tunings', were included in an unofficial 'LT-GEE Lessons & Resources' guide for users, provided as a project deliverable to support future regional use: https://cafri-labs.github.io/lt_resources/.

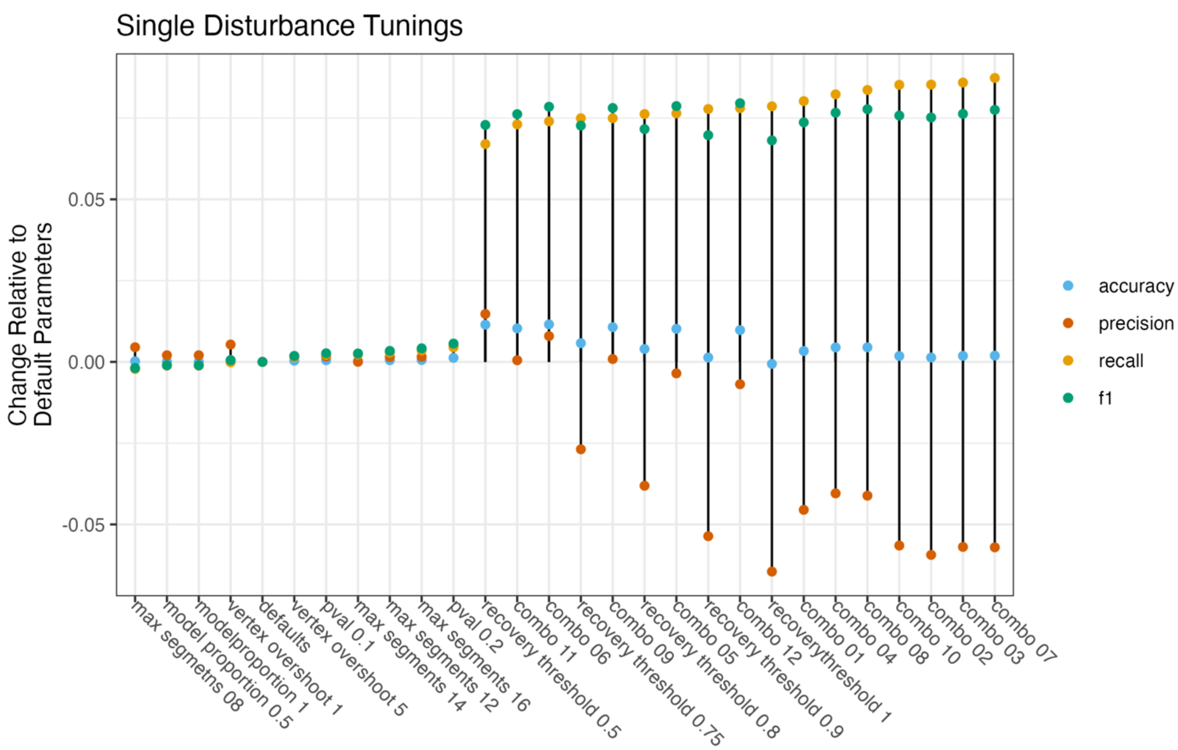


***Figure 3****. Results of tuning parameter combinations for single disturbance detection. Plot indicates net changes in algorithm performance metrics (accuracy, precision, recall and F1 score) for each parameter set (or tuning), relative to LT-GEE default values.*

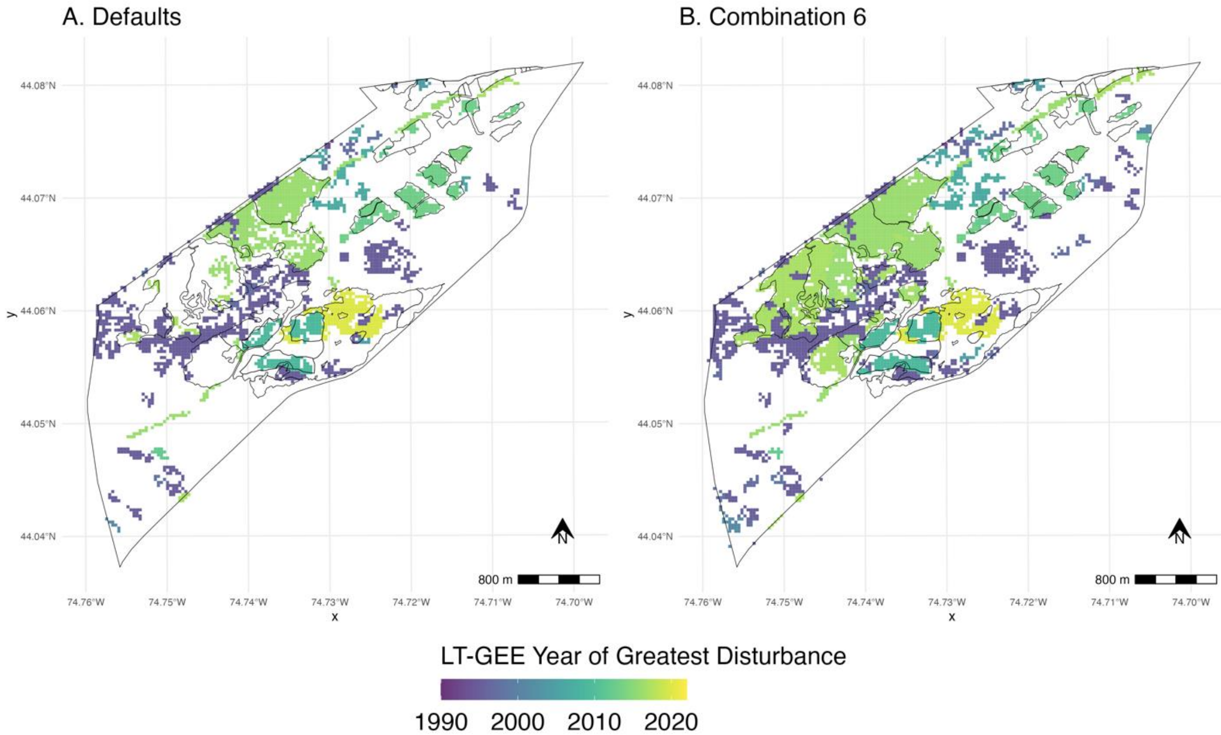


***Figure 4****. Example of improved harvest detection between LT-GEE default parameters and one of the top-performing parameter sets, or tunings, developed in this study (known as combination 6). Black line polygons indicate harvest units within the larger parcel boundary.*

**2. High resolution (30m) map products of forest disturbance for the FEMC service region**

To produce a set of regional map products depicting historical disturbance patterns since 1990, in consultation with FEMC staff, we selected three LT-GEE tunings to generate outputs (disturbance maps). The first tuning provided the best possible harvest detection that we could achieve with LT-GEE and available reference data; however, it may not detect some very small-scale or ephemeral canopy disturbances and may be less suitable for mapping natural disturbances. The second tuning features a very short recovery period (1 year) that makes the algorithm much more sensitive to smaller and shorter-term disturbances, such as insect defoliation events (Fig 4). The third tuning represents a midpoint between the high specificity of the first tuning and the high sensitivity of the second. Using these algorithm configurations, we generated LT-GEE outputs for the entire region (NY, MA, CT, RI, VT, NH, ME) that include year of greatest disturbance, year of most recent disturbance, total disturbance frequency (1990-2022) and the magnitude (change in spectral index value) of the greatest disturbance. These 30m map products were archived on the FEMC website as multi-band raster 'stacks' with metadata compliant with FGDC, OGC and ISO standards.

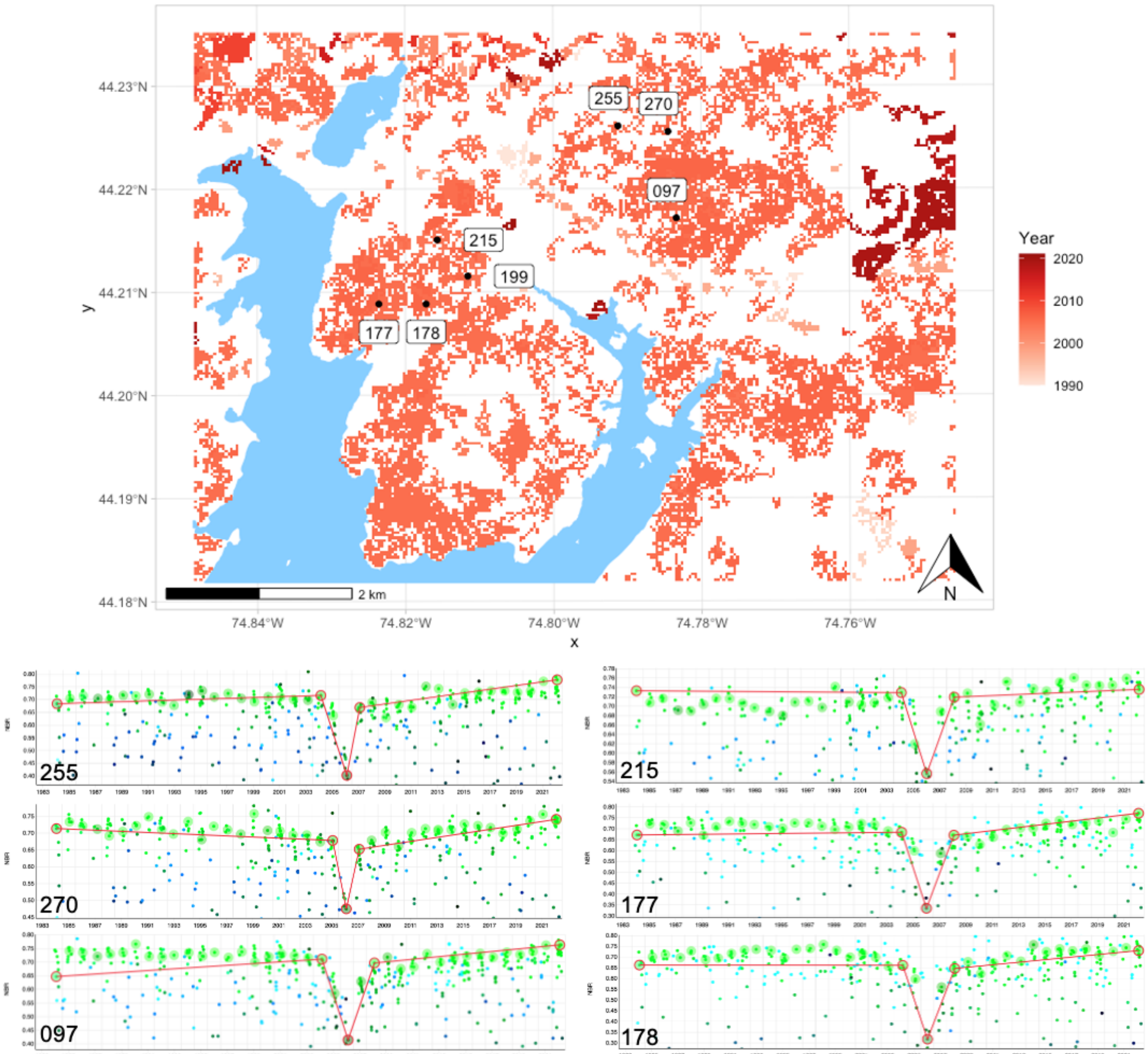


***Figure 5.*** *LT-GEE detection of a single-year disturbance (2006) in the Adirondacks (near Raquette Lake, NY), likely due to a well-documented forest tent caterpillar outbreak that year in the region. Map (upper half) depicts pixels where defoliation was detected and the line and dot plots (lower half) represent time-series spectral index (NBR) at six example pixels, labeled by numbers in the reference map. Time-series plots were constructed using TimeSync based on Landsat c1 imagery.*

## 3. Uncertainty estimates for map products at native resolutions

Performance estimates derived from our tuning procedure, such as overall accuracy and precision, were mostly relevant to detection of harvest activities. Similar estimates of accuracy, precision, etc. for non-harvest disturbances could not be generated because of the very limited field reference data available on 'natural' disturbances. We attempted to generate new field reference data with substantial field work and image-based validation efforts, with some success, but simply did not end up with enough observations to reliably estimate accuracy. The overall lack of spatiotemporal data on 'natural' disturbances is both why we need tools like LT-GEE, but also why we (and others) struggle to validate their outputs with 'ground-truth' information. As a result, we can say that our harvest detections are between 90-95% accurate, but we cannot currently estimate this for non-harvest disturbances. Our best estimate of accuracy for non-harvest disturbances was closer to 70-75% based on a limited reference set that combined imagery (TimeSync) and field observations.

**4. A brief 'users guide' for mapping disturbance and change in US Northeast forests using Landtrendr on Google Earth Engine (LT-GEE)**

Our unofficial LT-GEE Lessons & Resources guide includes beginner-level technical content on:

- Getting Started with LT-GEE
    - Recommended papers and resources
    - Understanding algorithm parameters
    - Selecting imagery
- Tuning LT-GEE
    - Methods
    - Recommended Tunings
- Time Sync
    - Using TimeSync
    - Alternatives to TimeSync
- Tips & Tricks
- Code
    - Google Earth Engine API scripts
    - Accuracy Assessment (Project R)

This online resource was created to encourage and support the broader adoption and application of LT-GEE in forest landscape science and stewardship efforts across the US Northeast region. We feel Landtrendr is a promising tool, although there remains room for improvement, which can take place as it (hopefully) becomes more frequently used in the region. Along with sample data products (e.g., historical forest change maps) with wall-to-wall coverage of the FEMC region, we created the user guide to facilitate technology transfer from this project. Note this deliverable substitutes for the 'citizen science field guide' in our proposal that, after some reflection on our field campaign and discussions with FEMC staff, was deemed to be much less useful overall.

**Additional Products & Outcomes**

This project primarily supported the training of a Master of Science student in Forest Resources Management at SUNY ESF, Madeleine Desrochers, who graduated with her MSc in May 2024 and is preparing to submit two journal manuscripts from her thesis: 1) mapping historical disturbance regimes and trends in reserve forests of the Adirondacks (NY), and 2) change attribution models for classifying harvest vs non-harvest disturbances, based on LT-GEE outputs. Four more graduate students at ESF contributed to this project, two as field crew and two as coders/analysts. Project outputs, included maps and tunings, have been directly incorporated in ongoing forest carbon mapping and monitoring via the NY Forest Carbon Assessment led by CAFRI. In turn, this work contributed to CAFRI data products shared with public and private sector partners across NYS.

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