Vegetation Cover Change Detection via NDVI Trend Analysis

Methodology

Gabriele Pizzi

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1 Abstract

This document details the scientific methodology for detecting multi-decadal vegetation cover change (1985–2025) using harmonized Landsat time series. The classification system employs NDVI (Normalized Difference Vegetation Index) thresholds derived from USGS standards and linear trend analysis parameters adapted from peer-reviewed literature (e.g., Peng & Gong, 2025).

2 Introduction

Vegetation monitoring requires consistent definition of land cover states. This methodology implements a standardized taxonomy based on biophysical thresholds to classify vegetation density and change dynamics over a 40-year period.

2.1 Applicability Scope

This methodology is calibrated for temperate and Mediterranean ecosystems. Users should note that optimal NDVI thresholds vary by latitude and biome (Pettorelli et al., 2005).

3 Data Processing

3.1 Satellite Imagery

Collection 2, Level-2 Surface Reflectance data from USGS:

- Landsat 5 TM (1984–2012)
- Landsat 7 ETM+ (1999–2025)
- Landsat 8 OLI (2013–2025)
- Landsat 9 OLI-2 (2021–2025)

All imagery is processed at native 30-meter spatial resolution.

3.2 Quality Masking

Cloud and cloud shadow contamination is removed using the QA_PIXEL quality assessment band following USGS Collection 2 specifications:

- Bit 3 (Cloud) = 0 (clear sky)
- Bit 4 (Cloud Shadow) = 0 (no shadow)

Only clear observations are retained for NDVI calculation, ensuring temporal composites represent actual vegetation conditions rather than atmospheric artifacts.

3.3 Harmonization

3.4 Spectral Harmonization

Landsat 8/9 OLI spectral response differs from Landsat 5/7 TM/ETM+. Following Roy et al. (2016), band values are harmonized to ensure temporal consistency using Ordinary Least Squares (OLS) regression coefficients.

Table 1: OLS Transformation Coefficients (Landsat 8 to 7 equivalent)

Band	**Slope (m)**	**Intercept (c)**
Red	0.9785	−0.0095
Near-Infrared (NIR)	0.9548	+0.0068

Harmonization Protocol:

- **Landsat 5 & 7**: Treated as spectrally compatible (no transformation).
- **Landsat 8 & 9**: Transformed using $\mathrm{L7_{eq}} = m \times \mathrm{L8} + c$.

This correction reduces cross-sensor discontinuities that could otherwise be misinterpreted as vegetation trends.

4 NDVI Classification Thresholds

The core classification relies on absolute NDVI values to define vegetation states.

4.1 Threshold Verification

The selected thresholds align with U.S. Geological Survey (USGS) standards for Remote Sensing Phenology:

Table 2: NDVI Classification Thresholds

Class	**NDVI Range**	**Standard Interpretation**
Dense Canopy	≥ 0.6	Dense forest, healthy vegetation
Transitional	0.4 – 0.6	Open woodland, shrubland
Sparse	0.2 – 0.4	Grassland, senescing crops
Bare	< 0.2	Soil, rock, snow, water

4.1.1 Dense Canopy (≥ 0.6)

The USGS explicitly states that “dense vegetation such as that found in temperate and tropical forests… typically exhibits NDVI values of approximately 0.6 to 0.9” (USGS, n.d.). This threshold is the primary basis for defining the “Dense Canopy” class.

4.1.2 Sparse Vegetation (0.2 – 0.4)

USGS defines "shrub and grassland" as typically falling between 0.2 and 0.5 (USGS, n.d.). This methodology uses 0.2–0.4 for sparse and 0.4–0.6 for transitional to segment this broad range.

Design Decision: The subdivision at 0.4 NDVI is a methodological choice to separate sparse from transitional vegetation classes. This specific threshold is not independently validated in peer-reviewed literature and may require regional calibration for optimal performance in non-temperate ecosystems.

5 Trend Analysis

5.1 Linear Trend Computation

Trends are calculated using Ordinary Least Squares (OLS) regression on annual summer median composites.

$$\beta = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - \left(\sum x\right)^2}$$

Where:
- β = slope (NDVI change per year)
- x = year (1985, 1986, ..., 2025)
- y = summer median NDVI for year x
- n = 40 (number of years in analysis period)

5.2 Trend Significance Thresholds

To separate natural variability from significant change, a slope threshold of ±0.005 NDVI/year is applied.

Table 3: Trend Significance Thresholds

Trend Class	Slope Threshold
Gaining	$> +0.005$/yr
Stable	± 0.005/yr
Losing	< -0.005/yr

5.2.1 Scientific Basis

This threshold is derived from Peng & Gong (2025), whose analysis of spatiotemporal NDVI changes classified slopes between 0.005 and 0.016 as "moderate improvement" and defined the stable range as -0.007 to 0.005. This provides a peer-reviewed basis for the cutoff.

5.2.2 Momentum Analysis

To detect acceleration or deceleration in recent vegetation change, a secondary 10-year trend (2015–2025) is computed and compared to the 40-year baseline trend. This momentum indicator identifies whether change is intensifying or moderating:

Table 4: Momentum Classification Criteria

Momentum Class	**Condition**
Accelerating	Recent slope > Long-term slope + 0.002
Consistent	|Recent slope - Long-term slope| < 0.002
Decelerating	Recent slope < Long-term slope - 0.002

The 0.002 NDVI/year threshold was selected to distinguish meaningful acceleration from noise while remaining sensitive to ecological change dynamics. This dual-timeframe approach helps identify recent shifts in land management or climate-driven vegetation responses.

6 Classification Taxonomy

The system intersects absolute state (NDVI) with directional trend (Slope) to produce 9 mutually exclusive classes:

6.1 Trend-Driven Classes ($> \pm 0.005$/yr)

Table 5: Trend-Driven Classification Matrix

Class	**Definition**	**Transition Logic**
Canopy Establishment	Sparse/Bare → Dense	Crossed 0.6 threshold
Emerging Biomass	Sparse → Trans (+Gain)	Early recovery phase
Canopy Thickening	Trans → Dense (+Gain)	Maturation phase
Canopy Densification	Dense → Dense (+Gain)	Increasing biomass
Canopy Loss	Dense → Sparse/Bare	State collapse
Canopy Thinning	Dense → Trans (-Loss)	Gradual degradation

6.2 Canopy Establishment Epochs

For areas classified as “Canopy Establishment” (Sparse/Bare → Dense), the specific time period when dense canopy was first achieved is tracked using seven 5-year epochs:

Table 6: Canopy Establishment Epoch Definitions

Epoch Label	Time Period	Interpretation
1990	1990–1994	Early establishment
1995	1995–1999	
2000	2000–2004	Millennium era
2005	2005–2009	
2010	2010–2014	Recent decade
2015	2015–2019	
2020	2020–2025	Latest period

The baseline period (1985–1989) is excluded from epoch tracking as it serves as the initial reference state. The 5-year interval balances temporal precision with data availability, ensuring sufficient cloud-free observations for robust NDVI composites within each epoch.

6.3 Stable/Edge Classes ($< \pm 0.005$/yr)

Captures slow transitions often found at forest ecotones:

- **Edge Expansion**: Sparse → Trans (Stable)
- **Edge Colonization**: Trans → Dense (Stable)
- **Edge Retreat**: Dense → Trans (Stable)

7 Limitations & Caveats

Users must acknowledge the following limitations when interpreting results:

1. **Threshold Universality**: While the 0.6 threshold is standard for temperate/tropical forests (USGS, 2025), boreal or dryland forests may require lower thresholds (e.g., 0.5).
2. **Linearity Assumption**: Vegetation recovery often follows a sigmoid curve. Linear regression provides an average rate but may underestimate rapid recovery phases.
3. **Sensor Homogeneity**: Despite harmonization (Roy et al., 2016), minor spectral differences between Landsat generations may influence trend calculations in subtle ways.

8 Code Availability

The complete source code, including the Google Earth Engine script and documentation, is available at:

https://github.com/gbrlpzz/ndvi-vegetation-cover-change

This implementation was developed using the Google Earth Engine JavaScript API via the Code Editor interface (tested as of December 2025). While GEE maintains backward compatibility, users should be aware that API updates may occasionally require minor code adjustments for future compatibility.

9 References

Peng, Y., & Gong, H. (2025). Analysis of Spatiotemporal Changes in NDVI-Derived Vegetation Index and Its Influencing Factors in Kunming City (2000 to 2020). *Forests*, 16(12), 1781. https://doi.org/10.3390/f16121781

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J. M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution*, 20(9), 503–510. https://doi.org/10.1016/j.tree.2005.05.011

Roy, D. P., Kovalskyy, V., Zhang, H. K., Vermote, E. F., Yan, L., Kumar, S. S., & Egorov, A. (2016). Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity. *Remote Sensing of Environment*, 185, 57–70. https://doi.org/10.1016/j.rse.2015.12.024

U.S. Geological Survey (USGS). (n.d.). *NDVI, the Foundation for Remote Sensing Phenology.* Retrieved December 5, 2025, from https://www.usgs.gov/special-topics/remote-sensing-phenology/science/ndvi-foundation-remote-sensing-phenology