Applying the Landsat Archive to Detect Ecological Thresholds in the West African Tropical Forests

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Upper Guinean Forest of West Africa

- West African tropical forest (Upper Guinean forest)
  - ≈ 10.9 million ha
  - a globally significant biodiversity hotspot
  - vital resource for region’s wellbeing
  - Also under intense stress due to land use and climatic pressures
Upper Guinean Forest

- Remaining remnants contained in protected areas, which are embedded in a hotspot of climate stress & land use pressures, increasing their vulnerability to fire
Hypothesis

In the semi-deciduous tropical forest zone, increased fire activity has compromised forest resilience by pushing the system past a tipping point to an alternative stable state in which a novel ecosystem with low tree density is maintained by fire.

Ecological thresholds (Regime shifts) : Ball-and-valley diagram

A & B  Alternative ecosystem states

Ecosystem regime
Using Landsat data to detect regime shifts

*Look for components underlying regime shifts:*

1. **Trigger**: Detect sudden large disturbances that directly affect ecosystem states;
2. **Positive feedbacks**: Map vegetation changes and identify novel feedbacks which reinforce new vegetation states; &
3. **Hysteresis**: Map to demonstrate that alternative vegetation states exist under similar environmental conditions.
Study area

Four forest reserves in the semi-deciduous tropical forest zone of Ghana
Data

• 26 Landsat images, p/r =195/55, 1984 – 2015
  – Landsat TM/ETM+ imagery, surface reflectance
  – Source: USGS-EROS
  – Spatial resolution 30m

• Precipitation
  – Historical precipitation data from 3 weather stations in Ghana, 1976-2013
  – Source: Ghana Meteorological Service

• Field-based datasets
  – Forest inventory data in the 4 forest reserves:
    – Historical: 1986–1990
    – Current: March 2014

• Field points of current land cover, 2013-2014
Methods

• Generate time series:
  – Tasseled Cap brightness, greenness & wetness indices
    • the normalized spectral distance of a given pixel from a
      nominal “mature forest” class to a “bare soil” class.
  – Normalized burn ratio (NBR), dNBR & burned area

• Conduct time series analyses (trends and breakpoints)

• Summarize forest inventory data
Results: Burned area time series

Landsat Percent Burn Area

Immediate post-fire burn severity 1989

Trigger
Feedbacks & hysteresis

- Pamu Berekum and Tain II have poor forest condition: low tree density, basal area, & canopy cover
Colors represent a gradient from closed forest (green) to degraded forests or low vegetation cover (blue). Red color represents recently burned sites; white spaces indicate non-vegetated surfaces or no data.
Feedbacks & hysteresis: current alternative vegetation states in study area

A) Unburned forest

B) Recently (& frequently) burned

C) Transition to shrub-dominant vegetation

D) Transition to grass-dominant vegetation
Hysteresis: Precipitation trends

- Conditions have not become drier
- Northern and southern reserves have similar rainfall regime, but different fire regimes
- Increased fire activity in northern reserves not driven by drier climate
Summary of Results

• Late 1980’s widespread and severe burning was a trigger for declining forest cover in the two northern reserves

• The disturbed reserves transitioned to pyrogenic grass and shrub dominated vegetation, maintained by fire-vegetation positive feedbacks

• Despite a generally increasing precipitation, non-forested conditions persist in burned forest, suggesting a hysteresis effect
Role of the Landsat archive

• Scarcity of data on large scale disturbances & long-term records have constrained empirical studies of fire-driven regime shifts in tropical forest

• By leveraging the Landsat archive (1984-present), we were able to explore an important ecological question on ecosystem regime shifts in the tropics that would not have been possible otherwise.
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