

Identifying potential critical transitions in a forest ecosystem using satellite data

Ecosystems can undergo changes that are slow and gradual, or an abrupt change - a sudden nonlinear dynamics that can bring catastrophic changes and ultimately leads to the change in the structure and functioning. Non-linear and discontinuous changes sometimes may cause the system to shift into another undesirable state, called 'regime shifts' or 'critical transition'. The critical transitions occur at a point called 'tipping point' – defined as a point at which a change becomes significant (i.e. crosses the threshold) that a dynamic system suddenly switches to another state. Tipping points can cause drastic changes in ecosystems in a relatively short time-span. The scientific community has accepted the concepts of critical transition theory and methods to detect early warning signals of impending regime shifts or critical transition have been developed. These were focused on spatial and temporal indicators, such as autocorrelation-at-lag-1, skewedness and variance. However, most of these studies were based on theoretical and mathematical models, and lack an empirical base. Therefore, this study attempted to identify potential critical transitions and tipping points in a real-world example by using time series of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images.

The research attempted to identify whether the areas with high levels of early warning indicators are undergoing critical transitions, and analyze if generic early warning indicators of tipping points - autocorrelation-at-lag-1, variance, and skewness increase before a critical transition in a forest ecosystem. In this study, we argue that time series of enhanced vegetation index derived from MODIS satellite images can help to identify potential tipping points and critical transitions. The long term increasing trend and changes in the statistical properties of the observed time series of metric-based early warning indicators of critical transition and tipping points - autocorrelation-at-lag-1, standard deviation and skewedness - are used to identify the potential transitions and tipping points.

This study was done in Northern Jarrah Forest (NJF) located in the Southwestern Botanical Province or bioregion of Western Australia, directly east of Perth. In this study, MOD13A1 Version 6 product for vegetation index and the MCD12Q1 land cover data were used. MOD13A1 data was used to prepare and extract the time series of ecosystem variable (EVI) and test early warning indicators of tipping points. MCD12Q1 Land cover data was utilized solely to extract area of interest (AOI). The extracted time series of EVI was used to test the early warning of critical transitions in the time series. All the operations were done in R using the functionalities of *raster*, *rts*, *MODISsp* and *earlywarning* packages.

The study quantified early warning indicators for the Northern Jarrah Forest (NJF) ecosystem, but the strongest signals did not flag any forest that showed any signs of an impending shift. In contrast, it largely identified the areas that were mined in the past and are susceptible to human interference and land use change. Some forest pixels are identified but it did not show any collapse while monitored using imagery from Google Earth at different time. There might be several

possible reasons why the results indicated a non-tipping forest. The possible false indication of tipping points was found possibly due to the environmental and climatic variability that might have triggered the rise in indicators to act as a source of false alarm of impending critical transition or tipping point, but alternatively, it could also be that NJF forest ecosystem is not yet close to tipping points i.e. forest is still resilient. The results show that detecting critical transitions and tipping points in real-world ecosystems may not be as promising and straightforward as suggested by model simulations. Future studies should focus on filling the gaps in evidences of tipping points in real world examples by analyzing high resolution and high frequency data, integrating remote sensing with process based approach dynamic vegetation models and validate the results with ground observations.

Keywords: critical transition, tipping point, early warning, EVI, time series

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