Moving from detecting past regime shifts to diagnosing critical transitions

M. Allison Stegner, Zak Ratacjzak, John W. Williams, Steve Carpenter

Background/Questions/Methods

Many ecosystems are expected to abruptly change over the coming decades, yet predicting abrupt change is challenging because ecosystem state-driver relationships can take many forms. In systems with alternative states, a small driver change can lead to a large irreversible state change called a critical transition. Methods for anticipating critical transitions, called Early Warning Signals (EWS), employ expected statistical changes in system dynamics as the system approaches a critical threshold. Analysis of long ecological time series, as recorded by paleoecological proxies from sediment cores, are a promising avenue for testing EWS methods and diagnosing causes of past abrupt regime shifts. However, data from sediment cores are subject to time-averaging, missing data, and uneven sampling. These processes are likely to affect EWS signals, but their effects are poorly understood.

Here we used a data simulation approach in which we built a model with alternative woodland-grassland states to simulate past abrupt changes and critical transitions. We then explored the impacts of alternative sedimentation regimes and sampling designs on two widely-used EWS—change in standard deviation and autocorrelation time—to assess how sedimentary processes transform EWS signals and the ability of EWS approaches to identify past critical transitions.

Results/Conclusions

The woodland-grassland model has alternative states and undergoes critical transitions resulting from gradual changes in carrying capacity, *K* (driven by precipitation). Abrupt changes to grassland can also result from sudden changes in *K*, which do not generate EWS.

The diagnostic ability of EWS is retained under linear models of sediment accumulation rate and time averaging, although performance varies among EWS metrics. Standard deviation is robust to time averaging: critical transitions can be distinguished from non-critical regime shifts when sedimentation rates are linear (uniform time averaging) or "broken stick," characterized by a sharp break between two linear sedimentation regimes. Conversely, autocorrelation time is not robust to paleoecological transformations: critical transitions are indistinguishable from other ecological changes under any sedimentation models examined here. Under exponential sedimentation, which is typical of upper columns of lake sediments still experiencing dewatering and compression, neither EWS effectively distinguishes critical transitions from other ecological changes. Subsampling sometimes improved diagnostics and never had a negative effect. These results suggest that under non-exponential sedimentation, and with adjusted discriminant thresholds, standard deviation is a broadly effective metric for detecting critical transitions in paleoecological records. These results are applicable to any time series subject to missing data or time averaging.