The possibility of detecting Early Warning signals from fluctuations, for Amazonian forest decline

AMAZALERT

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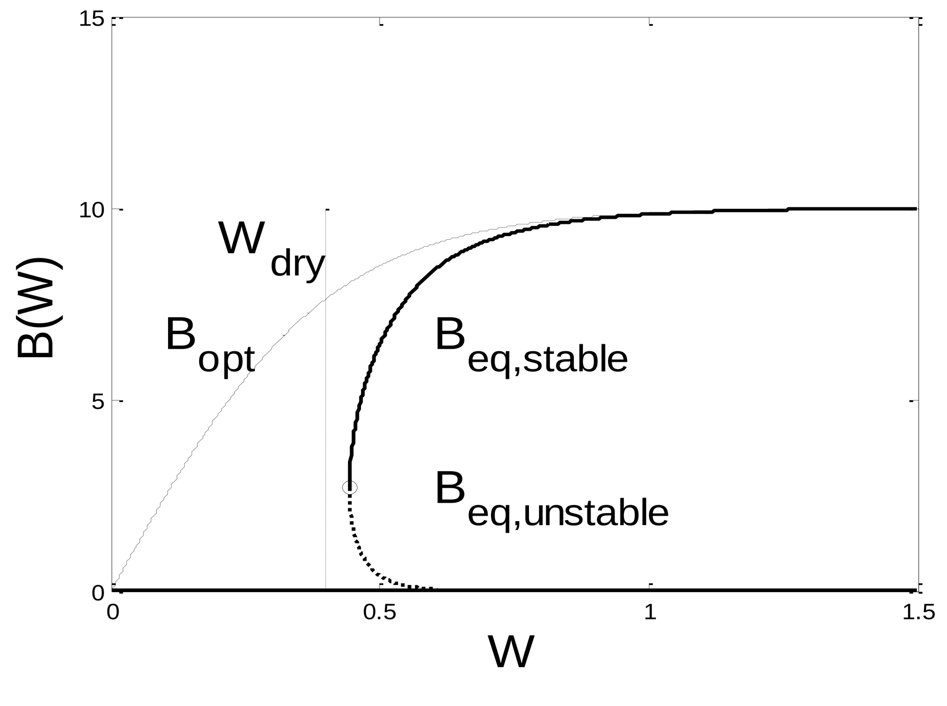
ALTERRA WAGENINGEN UR

Introduction

The use of fluctuation statistics (of e.g. biomass) is a possible avenue to explore Early Warning Signals (EWS) for Amazonian forest decline. Simple models predict that on approaching a critical transition, fluctuations in key variables may increase and so does the autocorrelation time. This phenomenon could be used for predictive purposes (as results from dynamical models remain uncertain).
However, there are a number of issues that need to be addressed before practical application can be considered.

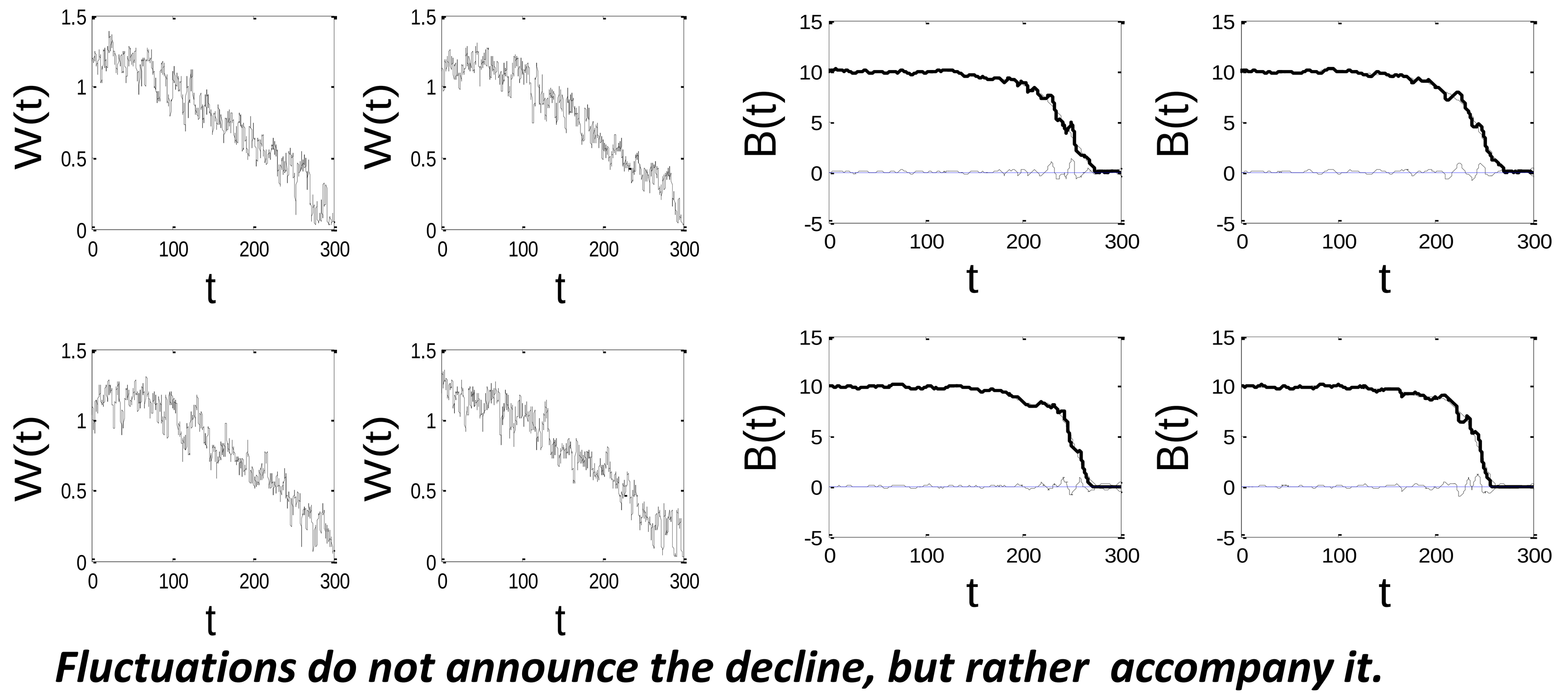
A simple model



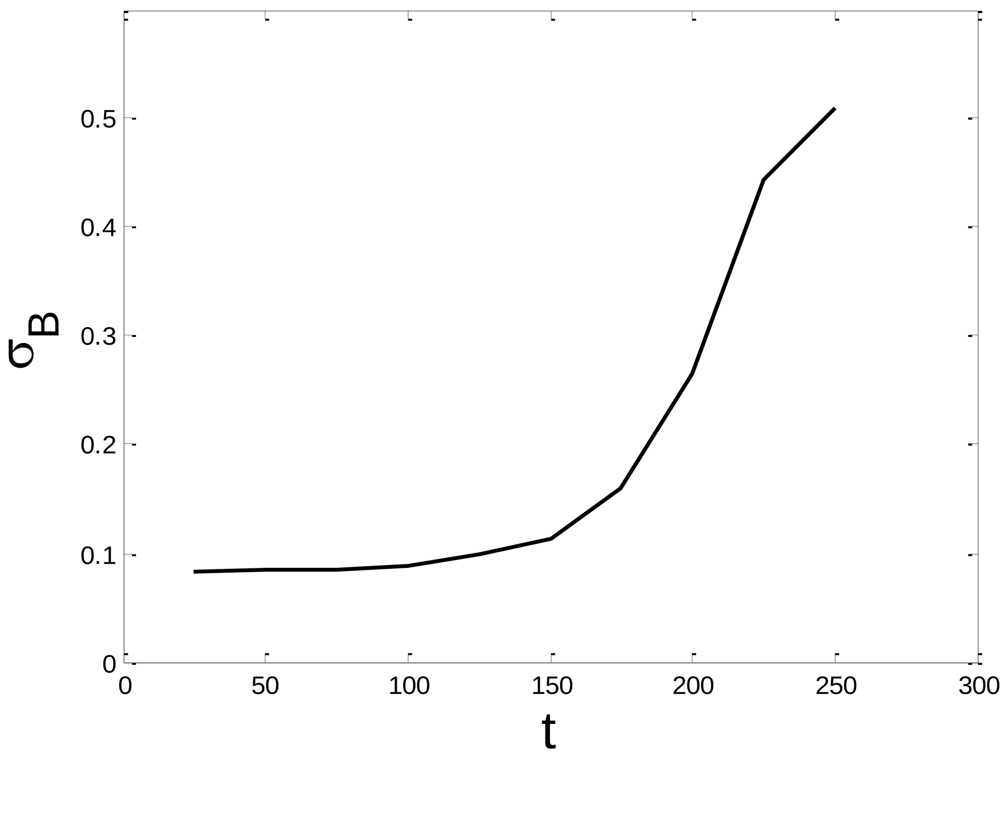
A model containing logistic growth, and a fire term (B_{opt} is the equilibrium without fire) was developed. Equilibrium biomass $B_{eq}(W)$ is a function of soil water content W. $B_{eq} > 0$ is only possible for W sufficiently large. At the critical point, a (tipping) transition occurs to the stable branch B = 0.

Model Experiments

Examples of times series for soil moisture W(t) ("input"), these differ only in the noise term specifying variability, and of the ensuing biomass B(t). Also depicted (in blue) is the isolated noise term in B(t).



Fluctuations do not announce the decline, but rather accompany it. They announce the irreversible stage of the decline (tipping).



Course of the ensemble-averaged amplitude in B(t), i.e. the fluctuation in biomass.

Theory

$$\frac{dB}{dt} = \lambda(B - B_{eq}(W))$$

λ ("eigenvalue") < 0 for stable equilibrium, and λ → 0 as the tipping point is approached.
The theoretical formula for the amplitude of B-fluctuations caused by W fluctuations is (ω = 2π /period):

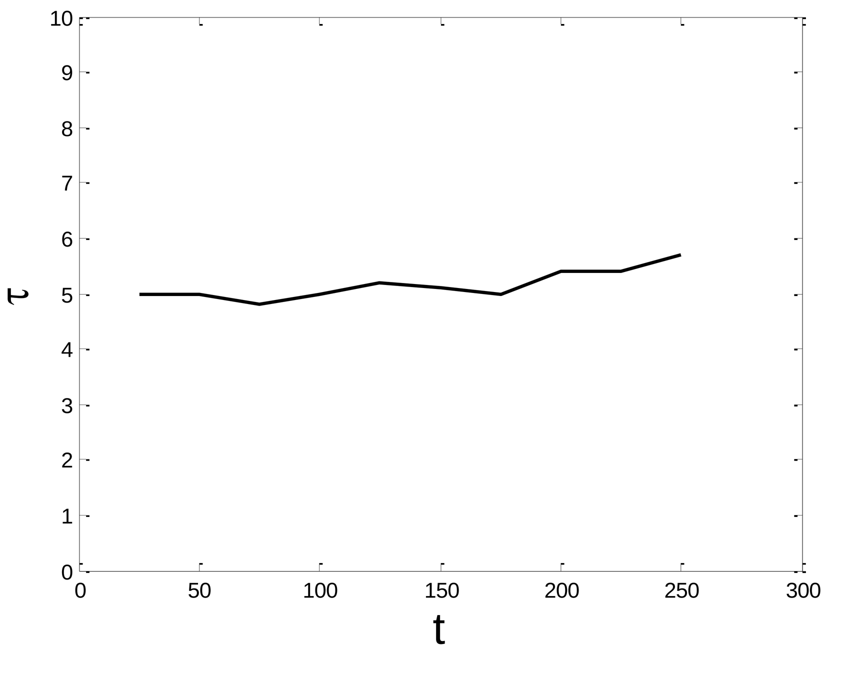
$$B_{amp} = \frac{1}{\sqrt{\lambda^2 + \omega^2}} \left| \lambda \frac{dB_{eq}}{dW} \right| W_{amp}$$

Issues with early warning from growing fluctuations:

- Fluctuations can grow if the slope dB_{eq}/dW grows for any reason : *false alarm possible*.
- Less usual: Fluctuation growth can be suppressed if dB_{eq}/dW shrinks: *missed alarm possible* (for these two points see also Dakos et al. 2012).
- Very large fluctuations can cause unpredictable tipping (Lenton 2011. Not occurring in these experiments)

Alternative: Look at the behaviour of the autocorrelation time τ. This always scales with 1/λ, so it blows up only on approaching a critical transition, without dependency on dynamic details (such as dB_{eq}/dW).

Model Experiments, result for autocorrelation time τ



In our experiments hardly any growth is seen !
Reasons:
- Short period fluctuations do not contribute to a growth of τ.
- Long period fluctuations cannot develop (or be resolved) because *their period is too long compared to the time scale of the decline* (see also Boulton et al 2013).

With an experiment with much slower decline of W and B, the expected growth of τ is well visible (not shown).

Conclusions

- An Early Warning System for irreversible transitions, based solely on detecting fluctuations, is not promising for the Amazon forest (for several reasons), on a policy-relevant time scale.
- More perspective may come from methods based on monitoring vegetation state, productivity, mortality, fire, regeneration; and monitoring soil moisture etc. in relation to dangerous thresholds (not discussed here). This will require extensive observations.