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Earth System Dynamics Discussions

Interactive comment on "Early warning signals in complex ecosystems" *by* I. S. Weaver and J. G. Dyke

Anonymous Referee #2

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The manuscript uses an abstract set of multidimensional, coupled nonlinear ODEs to model a conceptual ecosystem. They find the model has fixed point solutions and these fixed point solutions can loose stability through local bifurcations when parameters are varied via critical slowing down. They confirm this (i) by analytical computation of the fixed point and its Jacobian using the model equations directly and (ii) by computing the usual early warning signals of impending local bifurcations autocorrelation, variance and skewness of numerical simulations of the variable's time series.

The technical content of the manuscript as far as I can tell is free from error. However, with regard to early warning signals (EWS), which seems to be the focus of the manuscript as indicated by the title and the abstract, I do not see any new results. The analytical equations are presented in the manuscript and can be determined to have

fixed points whose stability via the linearised dynamics (given by the Jacobian) can be calculated. As a parameter is varied the smallest negative eigenvalue of the Jacobian, which determines the recovery time, will tend towards zero as it approaches a local bifurcation. This is well known (see for example any nonlinear dynamics text book). The EWS autocorrelation and variance are just functions of the eigenvalue of the linearised dynamics and this is also well known (Held Kleinen, 04) so I don't see any novelty here. The calculation of the EWS via numerics therefore seems unnecessary as it confirms what is already demonstrated in the analytics. Skewness is related to the locally dominant nonlinear term in the dynamics and one may get more information about the bifurcation. This is discussed but not very clearly. See Sieber and Thompson (2012) for work in this direction. Again, this can be investigated directly from the equations presented making the numerics unnecessary.

The authors may argue that as this is a multidimensional set of equations this is not necessarily expected which is true. Stability of an attractor can be lost through global bifurcations (no critical slow down), however their analytics indicate this is a local bifurcation which is defined through it's local stability. The authors only consider simple point attractors, rather than more exotic periodic or chaotic attractors that might be present in a multidimensional system. This is a direction the authors might consider investigating in a revised manuscript. It is also well known that in a multidimensional system, the eigenmode of the Jacobian with the eigenvalue closest to zero will dominate the dynamics effectively becoming one dimensional in most cases (see for example Held and Kleinen, 04 and Williamson and Lenton, 15). This is why in a complex, multidimensional world these techniques have any chance of being effective.

The main claims of the manuscript regarding early warnings are not novel, however the ecosystem model, depending on how much of it has been previously published, potentially is, although it is very abstract and difficult to map to specific systems. This may be interesting to biologists although I am unqualified to comment on this. Most of the manuscript is spent discussing this model. It appears the authors have published variants of this model mainly in biology journals. I wonder whether the paper would be a better fit in these journals? The manuscript here could fit in ESD under point 3 of the journal scope (Earth system interactions with the biosphere) although at a guess the emphasis should probably need to be more on the properties ecosystem model, its specific relevance to the Earth system and what is new in the manuscript.

I also concur with the other referee's comments although I regretfully struggle to suggest any obvious way to turn this into a publishable manuscript in ESD. This is not to say it is not possible. My recommendation is therefore to reject.

Some specific comments on parts of the text (in addition to ref 1):

- Intro: It seems the authors definition of critical transitions is defined as a loss of stability via a local bifurcation. At least this seems to be the only mechanism explicitly considered in the paper. It would be good to clarify this. Critical transitions can also happen via global bifurcations where CSD is not necessarily expected. Abrupt changes in states however can happen in many different ways not associated to bifurcations. This should probably be discussed. See Ashwin et al (2012) for more info.

- Section 2, line 6: systems approaching a critical point see increasing variance in state variables if stochastically perturbed. Only true if approaching a local bifurcation because of CSD.

- Section 2, line 13. Don't understand sentence starting 'This is referred...'

- Equation (3) does the term |.| denote vector norm? Seems this is the case but needs to be made clear in text.

- Lower case omega used in figure 3 not defined.

- Lots of figures, most seem unnecessary.

References:

H. Held and T. Kleinen (2004), Detection of climate system bifurcations by degenerate

fingerprinting, Geophys. Res. Lett., 31, L23207.

J. Sieber and J. M. T. Thompson (2012), Nonlinear softening as a predictive precursor to climate tipping, Phil. Trans. R. Soc. A, 370, 1205-1227.

M. S. Williamson and T. M. Lenton (2015), Detection of bifurcations in noisy coupled systems from multiple time series, Chaos, 25, 036407.

P. Ashwin, S. Wieczorek, R. Vitolo and P. Cox, (2012) Tipping points in open systems: Bifurcation, noise-induced and rate-dependent examples in the climate system, Philos. T. Roy. Soc. A, 370, 1166-1184.

Interactive comment on Earth Syst. Dynam. Discuss., 6, 2507, 2015.