Dynamical system modelling of human-environment interactions: the case of the Classic Maya collapse

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The collapse of the society of the Maya has found much attention in the literature and different theories about the collapse have been suggested in the past, especially regarding drought [1]. However, to date there is little quantitative modelling to test the consistency of the various hypotheses proposed. In this study we try to fill this gap by investigating the societal development of the Maya in the Southern Lowlands over a span of approximately 1400 years and exploring whether societal dynamics linked to depletion of natural resources can explain the rise and fall of the Maya civilisation. We propose a dynamical systems model that accounts for the state of the land, population and workers employed in swidden and intensive agriculture and monument building.

Recent models focused on the Maya collapse [2] show a sensitivity to changes in parameters that precludes robust prediction making. Furthermore, they do not address the issue of monument construction which could prove important in constraining model dynamics. In contrast to previous approaches, we explicitly compare our model output with the archaeological record for population growth and monument construction.

By optimising parameters related to demographic growth and shifts in agricultural specialisation we find that an excellent match to empirical time series of population, growth rates, and monument building can be obtained, provided a drastic increase in the usage of intensive agriculture is assumed to have occurred around 550 CE. When the harvesting rate increases beyond a certain point a (Hopf) bifurcation takes place that leads to large amplitude oscillations in the system. A similar conclusion has been reached for another model of a society that has collapsed, namely Easter Island [3]. The findings here lend support to a more general thesis that societal collapse can be modelled as a certain type of critical transition (supercritical Hopf bifurcation). Our results are found to be robust to sensitivity testing for a wide range of parameters. This qualitative picture persists even if including assumptions of droughts and drastic changes in precipitation.

[l] Douglas et al., PNAS **112**, 5607 (2015).

[2] Kuil et al., Water Res. Rese **52**, 6222 (2016).

[3] Roman, Bullock & Brede, Ecol. Econ. **132**, 264 (2017).