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Analysis

Profit fluctuations signal eroding resilience of natural resources

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ABSTRACT

A common pattern of environmental crises is a vicious cycle between environmental degradation and socio-economic disturbances. Here we show that while such feedbacks may give rise to critical transitions in social–ecological systems, at the same time they can offer novel opportunities for anticipating them. We model a community that has joint access to the harvest grounds of a resource that is prone to collapse. Individuals are tempted to overexploit the resource, while a cooperative harvesting norm spreads through the community via interpersonal relations. Both social and ecological collapses can be induced by environmental or socio-economic driving forces. Regardless of the type and cause of collapse we find that upcoming transitions may be detected using simple socio-economic response variables, such as individual profits. Our findings suggest that such alternative sources of information can be used to detect upcoming critical transitions in social–ecological systems. However, we also find that robust detection of critical transitions may be confounded by recovery attempts undertaken by resource users in the vicinity of an upcoming collapse, which may be falsely interpreted as a stabilization of the social–ecological system.

1. Introduction

Under present rates of environmental change, earth systems are facing an increased threat of undergoing extreme transitions on a global scale (Barnosky et al., 2011; Rockström et al., 2009). Species extinctions (Barnosky et al., 2011), desertification (Reynolds et al., 2007), and climatic shifts (Lenton et al., 2008) are only few examples of major changes that can have considerable effects on the delivery of ecosystem services and on the livelihood of people who depend upon them. Typically, the fate of ecosystems is highly linked to the practices exercised by the socio-economic systems around them (Berkes et al., 1998; Lade et al., 2013; Liu et al., 2007). For instance, the stability and resilience of common pool resources have been traditionally influenced by whether resource users succeeded in crafting institutional rules facilitating a cooperative sustainable exploitation regime (Baland and Platteau, 1996; Basurto and Coleman, 2010; Ostrom, 1990). However, identifying the causal links between ecosystem stability and social institutions is difficult, because changes in the ecological system have a profound effect on how the socioeconomic system will evolve (Aburto et al., 2014; Butzer, 2012; Diamond, 2005). Clearly, transitions of social–ecological systems (SES) are often the result of both natural and socio-economic processes.

In this paper we explore whether abrupt transitions can be anticipated in a coupled SES by estimating generic early-warning signals from the dynamics of both ecological and social subsystems. Our motivation to detect tipping points in SES is threefold. First, in order to understand how social–ecological transitions unfold and how we can manage them, it is essential to understand how social and ecological transformations mutually influence each other and to what extent they are mirroring the resilience of the SES as a whole. A recent work by Lade et al. (2013) has shown that ignoring the social side of SES severely underestimates the potential for abrupt transitions and in general it underscores the importance of coupled social–ecological dynamics. Second, tipping events are typically triggered by a lack of cooperation among users. These processes are changing over time depending on the state of the system (Levin et al., 2013). Hence, resource users will most likely adapt their exploitation strategy — for instance when a resource is increasingly depleted — making it difficult to predict the dynamics of the system. Third, there are multiple types of information that can be potentially used to infer risk of collapse of ecological resources. We focus on a strongly connected SES to show that tipping events can be reflected in the social part of the system, such as profits of resource users. In particular, our aim is to study the conditions under which detection of overexploitation is possible by indirect proxies of resilience.

Our work builds an important bridge between theoretical models of SES and empirical work that uses resilience indicators to anticipate upcoming transitions. While theoretical models of SES are invaluable tools to understand cross-scale feedbacks and explain patterns observed in

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real systems in hindcast, they are typically insufficient to detect potential upcoming transitions. Therefore, complementary approaches have been suggested to infer the proximity of a system to experiencing a potential transition. They include simple statistical signatures that can serve as early-warning signals for critical transitions (Dakos et al., 2012b; Scheffer et al., 2009) and that have been shown to anticipate abrupt changes in a variety of systems, like past climate shifts (Dakos et al., 2008; Lenton et al., 2008), extinctions in experimental microcosms (Dai et al., 2012; Drake and Griffen, 2010; Veraart et al., 2012), or even trophic cascades and eutrophication in whole lakes (Carpenter et al., 2011; Wang et al., 2013). These early-warning signals indirectly reflect the resilience of a system and thus are also referred to as resilience indicators (Dakos et al., 2012a; Scheffer et al., 2009). Fig. 1 shows intuitively how these indicators are supposed to change when a system is approaching a critical transition. Close to a critical transition, a system lies in a shallower basin of attraction and, therefore, becomes slower in recovering back to equilibrium after a disturbance compared to conditions far from the transition (Fig. 1A–B). This slowing down effect makes the dynamics of a system to show a rising variance (Fig. 1C–D) and an increasing autocorrelation at-lag-1 (Fig. 1E–F) that both reflect the level of resilience in the system and its proximity to collapse.

Despite the identification of these signatures prior to transitions in a variety of systems, there is still doubt on whether they can be applied in practice to timely detect an approaching tipping event (Biggs et al., 2009). In the majority of cases, this limitation is caused by the insufficiency of the data to robustly and timely diagnose the loss of resilience in the system (Dakos et al., 2012a). Therefore, we need to find ways to reduce this uncertainty and increase our options when it comes to the sources of data that might carry signatures of the impeding transition. Given the close association of ecological and socio-economic systems, it is interesting to consider whether socio-economic information may qualify as good proxy for detecting early warnings prior to critical transitions (Lenton, 2013). Our paper addresses this gap by offering insight on how resilience indicators may work in SES.

This paper is organized as follows. Section 2 presents the model of the coupled SES, clarifies the role of critical transitions, and explains how indicators of resilience are estimated. Section 3 presents the results, investigating the possibilities of how to anticipate critical transition. Finally, Section 4 concludes and discusses our findings.

2. Modeling Transitions in a Social–Ecological Harvesting Model

We use a modified version of the model of a SES developed by Richter et al. (2013) that considers a community having joint access to a common pool resource; see Fig. 2 for a conceptual overview. Following the literature on cooperation in social dilemmas, we assume that the community consists of two types of individuals: i) cooperators and ii) selfish individuals, i.e. defectors (Bulte and Horan, 2010; Sethi and Somanathan, 1996; Tavoni et al., 2012). While cooperators strive for a

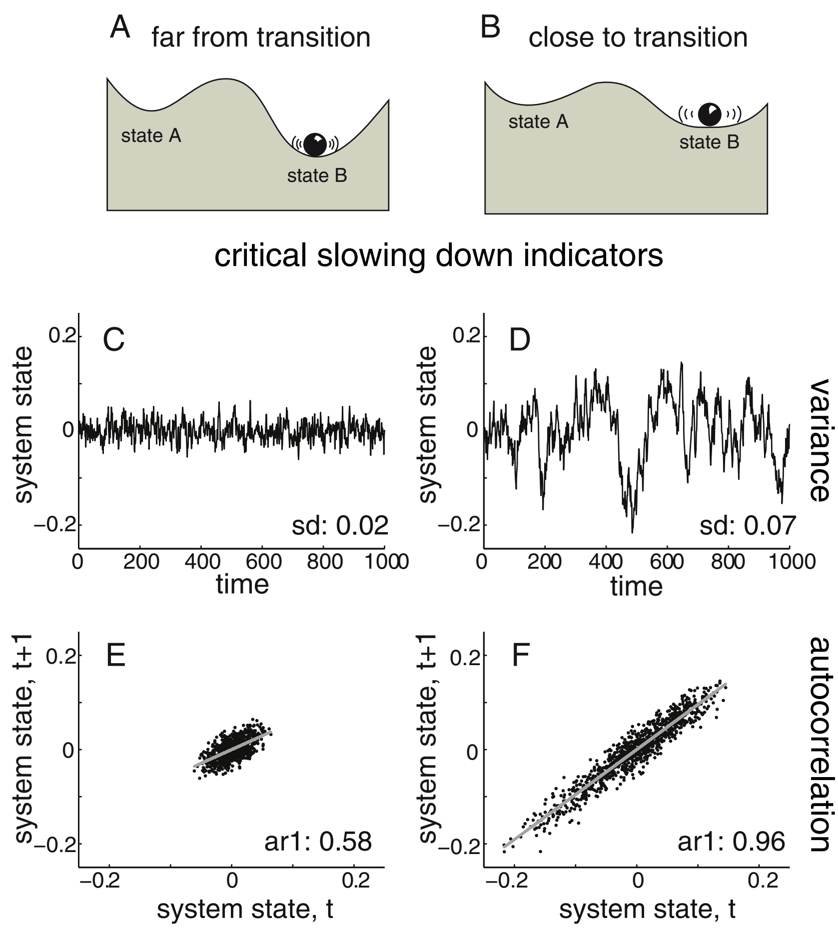

Fig. 1. Slowing down and early-warning signals of approaching transitions. Far from a transition, the system (ball) lies in a deep basin of attraction (valley) (A). If disturbed, the system returns swiftly back to its equilibrium position. Close to a transition, the same disturbance will cause the system to return slower back to its equilibrium position (B). This slowing down effect can be reflected in statistical properties from monitored time series of the system far and close to a transition. Variance increases close to a transition (the ball moves more freely around its equilibrium, and it is measured as SD standard deviation) (C–D). Autocorrelation at-lag-1 rises. In other words, the system starts to look more like its immediate past close to a transition (*ar1* quantifies the slope of the regression lines after fitting an autoregressive model of order 1, E–F). C–F shows simulated data from a stochastic model with a critical transition.