Science of the Total Environment 506–507 (2015) 164–181

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Poverty alleviation strategies in eastern China lead to critical ecological dynamics

Ke Zhang [a,1], John A. Dearing [a,*], Terence P. Dawson [b], Xuhui Dong [c], Xiangdong Yang [c], Weiguo Zhang [d]

[a] Palaeoecological Laboratory, Geography and Environment, University of Southampton, Southampton SO17 1BJ, UK
[b] School of the Environment, University of Dundee, Dundee DD1 4HN, UK
[c] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[d] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China

HIGHLIGHTS

- Lower Yangtze ecological and economic records reveal long-term system dynamics.
- Resilience in the regional social–ecological system declined from 1970s.
- Poverty alleviation led to losses of regulating ecosystem services.
- Modern regional system is in transient phase moving towards new steady state.
- Economic growth and ecological degradation are still coupled.

ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form 18 October 2014
Accepted 27 October 2014
Available online 19 November 2014

Editor: Daniel A. Wunderlin

Keywords:
Yangtze basin
Poverty alleviation
Agricultural intensification
Ecosystem services
Regime shift
Network connectivity
Environmental Kuznets curve
Paleoecological time series

ABSTRACT

Poverty alleviation linked to agricultural intensification has been achieved in many regions but there is often only limited understanding of the impacts on ecological dynamics. A central need is to observe long term changes in regulating and supporting services as the basis for assessing the likelihood of sustainable agriculture or ecological collapse. We show how the analyses of 55 time-series of social, economic and ecological conditions can provide an evolutionary perspective for the modern Lower Yangtze River Basin region since the 1950s with powerful insights about the sustainability of modern ecosystem services. Increasing trends in provisioning ecosystem services within the region over the past 60 years reflect economic growth and successful poverty alleviation but are paralleled by steep losses in a range of regulating ecosystem services mainly since the 1980s. Increasing connectedness across the social and ecological domains after 1985 points to a greater uniformity in the drivers of the rural economy. Regime shifts and heightened levels of variability since the 1970s in local ecosystem services indicate progressive loss of resilience across the region. Of special concern are water quality services that have already passed critical transitions in several areas. Viewed collectively, our results suggest that the regional social–ecological system passed a tipping point in the late 1970s and is now in a transient phase heading towards a new steady state. However, the long-term relationship between economic growth and ecological degradation shows no sign of decoupling as demanded by the need to reverse an unsustainable trajectory.

1. Introduction

1.1. Agricultural social–ecological systems

Poverty alleviation through agricultural intensification that increases trade opportunities and rural incomes has been achieved in many regions, but there is often only limited understanding of the impacts on ecological dynamics. Agricultural intensification is also seen as an essential component of ensuring global food security over the coming decades (Royal Society, 2009; Tilman et al., 2002). However,

* Corresponding author at: Geography and Environment, University of Southampton, Southampton SO17 1BJ, UK. Tel.: +44 2380 594648.
E-mail address: j.dearing@soton.ac.uk (J.A. Dearing).
[1] Present address: Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4811, Australia.

http://dx.doi.org/10.1016/j.scitotenv.2014.10.096
0048-9697/

the links between agricultural intensification, ecosystem services and the sustainability of social and ecological conditions, while known in general terms, are often difficult to gauge. For example, the apparent paradox between continued rises in wellbeing in the face of ecological degradation (Raudsepp-Hearne et al., 2010) is still not fully understood (Duraiappah, 2011; Nelson, 2011). While there is growing awareness that sustainable agriculture should be viewed from the perspective of adaptive and coupled social–ecological systems (Liu et al., 2007), the lack of long term data for regulating and supporting ecosystem services is also a major barrier to assessing the likelihood of sustainability or agricultural collapse (Costanza et al., 2007; Dearing et al., 2012a).

In a rapidly globalizing world, complexity theory suggests that agricultural intensification might be a process associated with increasing levels of connectedness across and between sub-systems, raising the chance of cascading failure and systemic collapse (Scheffer et al., 2012; Walker et al., 2009). Thus, a clearer understanding of how system network interactions are changing in rapidly developing agricultural systems would help to assess levels of resilience to external shocks and the likelihood of the tipping points that precede critical transitions (Biggs et al., 2012). The theory also indicates that a system may display early warning signals of impending instability and tipping points (Scheffer, 2009), potentially offering vital evidence for agricultural managers to modify strategy (Brock and Carpenter, 2006).

While there have been numerous calls to narrow the gap between complexity theory and its application to real world situations (e.g. Carpenter et al., 2009; Dearing et al., 2012a; Nicholson et al., 2009), progress has not advanced much beyond the implicit reference to system dynamics in frameworks for adaptive management (Dawson et al., 2010; Ostrom, 2009) and the development of more sophisticated social–ecological models (e.g. Lade et al., 2013). As a result, there are many calls for research that can quantify trade-offs between provisioning and regulating ecosystem services (e.g. UNEP, 2011), help anticipate tipping points and critical transitions (e.g. Carpenter et al., 2009), and provide an evidence base for policy-making based on complexity science principles. But there is little evidence for the successful application of complexity science in real world, regional, social–ecological systems to a level that provides new insight for sustainable management.

1.2. China as a case study

Spectacular economic growth over the past 30 years has made China the world's second largest economy, taking more than 600 million people out of poverty (World Bank, 2007). At the same time, environmental deterioration has become a major threat to China's future sustainable development (Liu and Diamond, 2005). With growing evidence for reduced crop yields (Guo et al., 2010; Ray et al., 2013), polluted water bodies (Gao and Zhang, 2010) and higher frequencies of extreme flood events (Dai and Lu, 2010) as unintended consequences of agricultural development, it seems that a conventional approach to environmental management in China is failing. As a result, the Chinese government has implemented environmental laws and policy (Wang, 2010), launched conservation and ecological engineering projects (Zhang and Wen, 2008), and driven institutional innovations (Liu and Diamond, 2008). Despite these measures, environment degradation cost around 3.8% of gross domestic product (GDP) in 2011, and the rate of growth in environmental costs exceeded the rate of GDP growth in 2009 (Chinese Academy, 2009). The main problem with these traditional policy responses is that they are essentially static measures lacking essential adaptive mechanisms that might weaken or dampen the positive feedbacks in the system that could lead to instability. A key question facing managers of rapidly changing social–ecological systems in China and elsewhere is how to develop a deeper, holistic understanding of system dynamical behavior that can underpin successful adaptive management strategies.

1.3. Study aims

A previous study of social–ecological change in the Lower Yangtze River Basin (LYB) region over the past 60 years, using lake sediment records (Dearing et al., 2012b), provided insight into the sustainability of the modern land use through analysis of ecosystem services (MEA, 2005). Here, we add new reconstructions and analyses of time-series for individual and aggregated (indexed) ecosystem services over the past decades for three rural counties (Huangmei, Shucheng and Wujiang) and the Yangtze tidal zone (Chongming), upscaled to represent the whole LYB: a total of 55 annually resolved time series representing the main trends in social, economic and ecological conditions since 1950, including representative trends for both provisioning and regulating services. Our aim is to develop an empirical, evolutionary approach to the study of the nonlinear dynamics of a rapidly changing region in eastern China that includes the rapidly growing cities of Shanghai and Nanjing. In doing so, we aim to quantify the long term trajectories of change, the levels of resilience and instability across the region, and the presence of tipping points at local through to the regional scales for input into management plans.

1.4. Locational context

For the purposes of the study we define the LYB as the area in the Yangtze River watershed lying east of Jiujiang City (29°41′37″ N, 116° 00′ 30″ E) within Hubei, Anhui, Jiangxi, Jiangsu, Zhejiang and Shanghai Provinces (Fig. 1). This river watershed area is ~122,000 km^2 with a main channel river length of ~940 km. The modern LYB represents 7% of total farmland in China with 10% of national crop production. Huangmei, Shucheng, Wujiang and Chongming Counties are located in the Hubei, Anhui, Jiangsu, and Shanghai Provinces respectively. Each county covers an area of ~1200 km^2 with ~1 M population.

Remote sensing data (Gu et al., 2009; Ning et al., 2010; Li et al., 2009; Yin et al., 2011: Zhu et al., 2007) from the past decades show increased areas of built-on land (45–198%) in all counties and relative losses of farmland (3–31%) in three of the counties (Tables A.1 and A.2). Agricultural intensification started in the 1980s with affordable fertilizers, herbicides and pesticides. Nitrogenous fertilizers have caused the acidification of soils leading to declines in wet paddy rice yields (Guo et al., 2010). The accelerated nutrient loading from fertilizers and dairy farm effluent to water courses, ponds and lakes is causing anoxia, recycling of phosphorus from sediments, eutrophication and lower fish yields (Gao and Zhang, 2010). Increased sediment delivery from soil erosion is reducing river channel volume, causing more destructive floods and more sediment delivery from bank erosion (Dai and Lu, 2010).

2. Materials and methods

2.1. Approach

It is conventional to reason (e.g. Costanza et al., 2007) that given a history of environmental degradation, regional social–ecological systems may gradually lose resilience and become vulnerable to either external events, like climate, or changes to internal dynamics that make regime shift more probable. What is not so clear in the literature is how to quantify the losses of resilience and changes in dynamics: what symptoms would a modern, vulnerable, regional social–ecological system be expected to show if it was close to a tipping point or had already passed a tipping point into a transient phase? Here, we identify lines of evidence for a number of systemic changes that together would provide a strong basis for considering the state of the modern system. These are: 1) evidence for long term trends in the degradation of supporting or regulating ecosystem services up to the present with known links to environmental management; 2) evidence for changes in the linkages or connections between system elements that are