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Who determines the trade-offs between agricultural production and environmental quality? An evolutionary perspective from rural eastern China

--Manuscript Draft--

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Keywords:	China; social-ecological systems, ecosystem services; evolutionary frameworks; trade-offs
Abstract:	We explore the evolutionary nature of interactions between government policy, farm decision-making and ecosystem services in Shucheng County, Anhui Province from 1950 to 2015. Analyses of ecological, social and economic trends are complemented by interviews with local farmers about their status, perceptions and attitudes. Since the introduction of the Household Responsibility System in 1980, the start of liberalisation, there has been a trade-off between rising levels of provisioning services and falling levels of regulating services in the environment, with some evidence that critical thresholds have been passed for water quality. Using a Framework for Ecosystem Service Provision, we argue that farmers have acted only as ecosystem service providers and have not influenced the national/regional policies that have brought about the trade-offs. Over the whole period, ecological degradation is best described as an example of 'creeping normalcy' where cumulative conventional actions by individual farmers produce unsustainable losses in regulating services. The Chinese government should be acting to balance the various ecosystem services through valuation and national policy. In this respect, there is a need for a new coordination of agencies that can deliver scientific and place-based advice to farmers that will allow them to maintain productivity levels while pursuing restorative actions. Even with new policies, the draw of urban employment and high production costs threaten the viability of farming in these marginal agricultural areas, especially over the next 10-15 years when most current farmers will retire.
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Response to Reviewers:	Ref.: Ms. No. TAGS-2018-0323 Who determines the trade-offs between agricultural production and environmental quality? A rural case study from eastern China International Journal of Agricultural Sustainability Authors' responses to Editor's/Reviewer's comments We thank the Editor and Reviewers for their comments that we agree will help improve the paper. Our response to each point raised is shown in italicized text below. 1.Please remove 'case study' from the title. Author response: We have changed the second phrase to "An evolutionary perspective

from rural eastern China”

2.The quality of the figures is very poor - this needs revision before the text goes to production.

Author response: We provide new high resolution files for each figure and have dealt with issues raised by Reviewer 2 below.

3. The reference list a little bit old(ish); please can you include up to date peer reviewed references including those published in 2019, throughout the text.

Author response: We have updated and added more recent references.

Reviewer #1: This is an excellent paper that is recommended for publication without revision.

Reviewer #2:
The paper is well presented and supported by a relevant bibliography. The figures are helpful, but in the pdf provided, the colours used result in poor differentiation and should be modified to make the trends easier to follow. The explanations of each should also be presented below each figure.

Author response: We have modified figures 3, 4 and 5 to make the lines more distinctive. Figure captions follow the Appendix and full explanations of each figure are given in the text. .

The paper follows the impact of policy, markets, and farming practices on livelihoods and environmental services over 6 defined phases pre- and post- the introduction of the Household Responsibility System on 1980. While to principal policy differences between the phases are outlined, given the significance of the HRS as the prime driver of change, the paper would benefit from a better description of all the elements of the HRS beyond the specific policy changes listed for each phase.

Author response: We have added new text (especially lines 153-158) to give more information about Phase I and Phase II (HRS)

Using lake water quality and sediment cores to track environmental change and as means to validate farmers perceptions is novel and valid. The separation between lowland and mountain communities shows an interesting differentiation in perceptions and farming practices. However given the challenges presented by urban migration and aging it might have been useful to have investigated whether women or younger interviewees held differing views/perceptions.

Author response: Yes with hindsight this would have been a good idea.

The findings and conclusions appear consistent with the data presented. They replicate trends found elsewhere in China - and globally. The paper claims that it will address 3 overarching question (74-82). It demonstrates clearly that farmers are rational and responsive to national policy changes and market opportunities. The survey shows that farmers are aware of changes in their environment; however the paper fails to record how farmers are responding to, or trying to address impacts of their practices on the regulating services.

Author response: We dispute this to some extent because we do record that farmers see the problems of deteriorating regulating services as a governmental responsibility. In the section ‘Views on ecological degradation’ we state “.....discussions with farmers revealed a dominant view that the responsibility for the degradation lies with the government, not with farmers themselves.” The bottom line is that we have little evidence that farmers actually do address the impacts of their own actions. However we do agree that this point should be emphasized and have added new sentences to this effect (Lines 562-564; 618-622; 655-657) in the Discussion and Conclusion.

Finally while advocating institutional and policy reform to address environmental challenges, the authors do not suggest how/what these might be - eg through PfES,

	education, publicity campaigns, regulation. Or precision and conservation agricultural techniques. Author response: We feel that these dealing with issues in more detail are beyond the scope of the present paper and constitute substantial topics in themselves. Any one of these topics could form the basis of another paper and some would require further research and fieldwork. We would prefer to leave these parts of the discussion unchanged.
Additional Information:	
Question	**Response**
Number of words	8464

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Abstract

We explore the evolutionary nature of interactions between government policy, farm decision-making and ecosystem services in Shucheng County, Anhui Province from 1950 to 2015. Analyses of ecological, social and economic trends are complemented by interviews with local farmers about their status, perceptions and attitudes. Since the introduction of the Household Responsibility System in 1980, the start of liberalisation, there has been a trade-off between rising levels of provisioning services and falling levels of regulating services in the environment, with some evidence that critical thresholds have been passed for water quality. Using a Framework for Ecosystem Service Provision, we argue that farmers have acted only as ecosystem service providers and have not influenced the national/regional policies that have brought about the trade-offs. Over the whole period, ecological degradation is best described as an example of 'creeping normalcy' where cumulative conventional actions by individual farmers produce unsustainable losses in regulating services. The Chinese government should be acting to balance the various ecosystem services through valuation and national policy. In this respect, there is a need for a new coordination of agencies that can deliver scientific and place-based advice to farmers that will allow them to maintain productivity levels while pursuing restorative actions. Even with new policies, the draw of

urban employment and high production costs threaten the viability of farming in these marginal agricultural areas, especially over the next 10-15 years when most current farmers will retire.

Keywords: China; social-ecological systems, ecosystem services; evolutionary frameworks; trade-offs.

Introduction

Warnings about the possible long term negative consequences of unsustainable farm practises (Raudsepp-Hearne et al., 2010) are partly borne out by global figures that show widespread stagnation and declines in grain yields (Mehrabi et al., 2019; Ray et al., 2012). However, the whole process through which agriculture is deemed to lie on a sustainable trajectory or not is complex. Sustainable agriculture depends not only on current top-down government policy and resource management strategies (Foley et al., 2011) but also on bottom-up decisions made by farmers in the light of national policy, markets and their knowledge about the environment (Duong et al., 2019; Fairweather et al., 2008). Farmers make decisions in response to less predictable short-term factors (Darnhofer et al., 2011), such as extreme climate events and energy costs, as well as to the likely impact of longer term trends, such as the emphasis in many countries on increasing crop yields through agricultural intensification (Garnett et al., 2013; Poppy et al., 2014; Pretty et al., 2018). In these ways, agriculture may be viewed as a complex system of ecosystem services with exogenous and endogenous drivers and pressures working through feedback mechanisms over a variety of timescales (Armstrong McKay et al., 2019; Zhang et al., 2018).

In the People's Republic of China, agricultural output in the period 1950-2015 rose five-fold (Li et al., 2013). This has been achieved through technological advances, including new high yielding crops, mechanisation, fertilizers, pesticides and irrigation. In addition, policy reforms have moved farming away from collective systems towards more independent commercial regimes. Government policies since 1979 mainly reflect two sets of concern: maintaining or increasing crop yields, particularly grains, and reducing the incidence of hazards, like flooding and soil erosion. In ecosystem service terms, these different motivations have focused on extracting provisioning goods and services, and on protecting regulating services respectively. However, despite efforts to protect the environment, the growth in production has been linked to widespread ecological degradation, particularly soil erosion, salinisation, desertification and water pollution (Liu & Diamond, 2005).

Our recent studies have highlighted the long-term trade-off between growing provisioning services and declining regulating services within the lower Yangtze basin (Dearing et al., 2012a; Lin et al., 2019; Zhang et al., 2015), and the widespread irreversibility of environmental degradation across China (Zhang et al., 2016). Indeed, a major challenge for Chinese agriculture is to find ways of maintaining or growing outputs while stabilising or reducing the ecological impacts. Chen & Du (2014) suggest that the socio-economic constraints could be reduced with economic development and changes in land tenure and land management. But to do this requires more detailed information about how past policies and reforms have affected the social-ecological systems in rural China.

Here we focus on one of those areas in the lower Yangtze basin, Shucheng County (hereafter Shucheng) in order to try and understand how trade-offs between rising production and deteriorating environmental quality have reflected the interaction of national agricultural policy and local farming decisions. Shucheng is an agriculturally marginal 'poverty-stricken' county with low levels of income, offering a chance to observe the environmental constraints on long term economic growth and poverty alleviation, and the possible negative consequences of environmental degradation. We have designed a research methodology that addresses the following overarching questions:

- How have national policies affected farming decisions and ecosystem services through time?

- Were local farmers able to perceive the environmental degradation and make restorative actions?

- Given the findings, what are the implications for designing or implementing appropriate policies over the next thirty years?

Materials and Methods

Shucheng County

Shucheng (area 2092 km^2) lies to the west of Chaohu lake in Anhui Province (Figure 1). The landscape of the county comprises the Dabie Mountains (52% area) in the west, a central hilly area (20% area), and alluvial plains (28% area) extending to the lake edge. The population of the county doubled between 1950 and 2000, from 489 500 to 983 379 (Chorography Compilation Committee of Shucheng County, 1995; Yan et al., 2009), and is currently ~1 million with 86% engaged in agriculture. As a result of reforestation since the 1960s, the total area under cultivation decreased from 507 km^2 (1950) to 416 km^2 (2009). The Green for Grain Programme (1999-2007) gave payments across China for ecosystem services in order to convert croplands on steep slopes to forest (Liu et al., 2014). Main crops are rice, wheat, cotton and rapeseed in the plains with rice, tea and chestnuts in the mountains, and vegetables near major towns. Labelled by the national government as one of the ~590 'poverty-stricken' counties of China, an annual farmer's income was (in 2008) approximately US$ 900. Despite reforestation of up to 65% of the steep slopes in Shucheng (Yuan et al., 2014; Yu, 2011; Zhang et al., 2010), soil erosion, river sedimentation, flooding and water pollution have at various times become serious problems (Dai et al., 2009), undermining poverty reduction activities and sustainable rural development.

Chinese agricultural policy 1949-2011

Since 1949, farmers in Shucheng, as in every Chinese county, have worked under the direct influence of national agricultural policy. Li et al. (2013) define six historical phases of national agricultural policy aimed at influencing grain production. From Phase I (1949-1977) to Phase VI (2011 onwards) there was a shift of direct control and responsibility from the government to the household. Phase I was a collectivised economy where farmers were given quotas for food production but no extra compensation for producing beyond the quota. The introduction of the Household Responsibility System (HRS) at the beginning of Phase II in 1978 reallocated land rights from the People's collectives to individual farms with the opportunity for farmers to sell surplus produce at a market price. During Phase II, farmers' quotas were reduced which gave further incentives to produce crops for sale at market prices. Phase III extended the liberalisation process with promotion of pesticides and fertilizers and non-grain cash crops through price controls. Phase IV (1999-2003) saw a drop in national grain production as farmers shifted their focus towards cash crops in response to the government leaving grain prices to be controlled by the market. In order to restore grain production, in 2004, the government removed agricultural tax and introduced subsidies for grain production (Phase V). Although national figures for grain production have been revived by these measures the rates of increase since then (Phase VI) are low relative to the large inputs of fertilizer and other resources (Li et al., 2013). The ongoing response to 'inefficient farming' is the reform of land management through Land Circulation (Li, 2010) involving aggregation of small fields into larger units that is designed to improve the economies of scale and incomes.

Some national fluctuations in historical grain production figures are therefore explained by changes in national policy (Xu et al., 2014). However, since 2000, there have been notable short- term fluctuations in annual yields that have led to speculation that agricultural production in some regions is now biophysically constrained by resource depletion, such as groundwater (Brown, 2013) or positive feedback mechanisms, like soil acidification (e.g. Guo et al., 2010). Other commentators (e.g. Li et al., 2013) argue that the slow increase in grain production in recent years is due to the lack of modern agricultural technology and methods. Indeed, results from field experiments across China (Chen et al., 2014) suggest that current yields of rice, wheat and maize could be raised by 18-35% through the adoption of integrated soil-crop system management practices though the results of a major field campaign trial puts these figures at a lower level, at about 11% (Cui et al., 2018).

Study approach

We take an evolutionary approach (Dearing et al., 2012b) that combines information on changes in national policy, farm activities and ecosystem processes over 65 years together with the views of current farmers. An evolutionary perspective is important for identifying the timescales of drivers, ecosystem states and human responses, understanding the nature of trade-offs between ecosystem services, and evaluating the extent to which a social-ecological system is contingent on past events and conditions, or even path-dependent. Such information can also help identify whether detrimental transitions (tipping points) in, for example, productivity or ecological states, have already occurred or inform on the likelihood of thresholds being transgressed in the near future. Transitions are often relatively rapid but may be the culmination of slow incremental change in some key process that are imperceptible without long term ecological monitoring (Zhang et al., 2007; Zhang et al. 2015), and may be costly to fix or even irreversible (Scheffer et al., 2012). In order to facilitate analyses, we embed the evolutionary approach within a Framework for Ecosystem Service Provision (FESP - Rounsevell et al., 2009) based on a modified Driver-Pressure-State-Impact-Response[1] (DPSIR) framework (Figure 1). The FESP integrates across multiple services and scales, makes explicit the exogeneous and endogenous drivers within the system, and, importantly, allows for feedback mechanisms that drive non-linear interactions.

Annual statistics for agriculture, population, economy and climate are available at provincial (1949-2008) and county levels (~1980s to 2008) giving time-series for provisioning ecosystem services and socio-economic-environmental drivers, but ecological monitoring of water quality and other ecological processes are, at best, available for recent years only. Regulating services are the most important in terms of determining the sustainability of land systems but are often poorly understood or under-represented in studies because of insufficient data. Therefore, we use laboratory analyses of lake sediments to allow the novel historical reconstruction of multi-decadal trends in major regulating ecological services within the upstream catchment and lake (Dearing et al., 2012a). Here, we use dated sediment cores

[1] Throughout the text we capitalize the first letter of terms referenced within the FESP.

sampled from Chaohu lake as proxies for decadal time-series of water quality, lake productivity, air quality, sediment quality, terrestrial biodiversity and soil stability.

We first describe the multi-decadal trends and use principal component analysis (PCA) and breakpoint analyses to reveal plausible long-term associations between Drivers, Pressures, States and Impacts (Figure 2). Second, we compare the temporal data against shorter term policy changes to tease out plausible links between Responses (policy decisions), Pressures, Impacts and States. Third, we interrogate the links between human behaviour and ecosystem services within States and Impacts through the results of a questionnaire survey, exploring how changes in ecosystem services are perceived by local farmers, how they currently assess their farming in terms of policy and income, and how they are planning for the future. Finally, we draw the findings together in addressing the research questions.

Time-series data and statistical analyses

Official annual statistical data for social, economic and agricultural changes were obtained for Shucheng, Anhui Province, and an average for of all China's Provinces from Statistical Year Books. Climate data were obtained from monitoring records in the nearby Hefei City located 50 km to the northeast of Shucheng (Figure 1). Sediment data were obtained (see Dearing et al. 2012a for full details) from sediment cores taken from the western side of Chaohu with a piston corer in 2006. Core sediments were subsampled at a 0.5 cm resolution for 0–50 cm and 1 cm resolution in deeper sediments. Sediment samples were dated using ^{210}Pb and ^{137}Cs radioisotopes, and a constant rate of supply model was used to calculate a chronology and depth-age curves for each core. Only data in the period ~1950-2006 are used in the present study. Typically, the dating errors are ±5 years (2 st. dev) for 1950 reducing to ±2 years in recent years. The sediments were analysed to produce the following proxies for ecosystem services:

- Sediment regulation proxy: dry mass sediment accumulation rates (SAR)
- Soil stability proxies: magnetic susceptibility and the Sr/Rb geochemical ratio.
- Air quality proxies: lead (Pb) and soot concentrations.
- Water quality proxies: diatom inferred-total phosphorus and total organic carbon (TOC).
- Biodiversity proxy: rarefaction indices for floristic richness in pollen counts.

Normalised data varying between 0 and 1 are used (Figure 3) so that trends can be easily compared and aggregated. The formula used for scaling the data series (x1:xn) to (0:1) is x1-(min x1:xn)/[(max x1:xn)-(min x1:xn)] where min and max are minimum and maximum values within the data range. In the case of biodiversity, values of 1 and 0 equate to highest and lowest levels of ecosystem service. For all other proxy records, like soil stability, values in the range 1 to 0 were inverted so that values of 1 and 0 equate to highest and lowest levels of ecosystem service respectively. Principal components analysis of the time-series data was performed and plotted by the *prcomp* and *ggbiplot* functions in R (R Core Team, 2017). Statistically significant ($p \leq 0.01$) breakpoints in time-series were calculated (Zhang et al., 2015) as evidence for shifts in system or sub-system states.

Questionnaires and focus groups

A questionnaire with closed and open questions was designed (see Appendix) to obtain information about current farming activities, farmer's perceptions of ecological degradation and their future plans. Farmers were selected randomly from towns situated in the two most contrasting landscape-farm systems across the county (Figure 2): mountains (Hepeng) and plains (Hangbu). The survey, conducted in August 2012, was administered to 68 farmers (33 from Hepeng and 35 from Hangbu). Trained university research students conducted face-to-face interviews with farmers at their house or at local agricultural offices, where interviews typically lasted 30 minutes. All the interviews were conducted on a voluntary basis, and farmers consented verbally to a written set of survey aims and the anonymous use of the collected data.

Results

Trends and statistical analyses

Trends for the main Drivers, Pressures and Impacts within the system show (Figure 3) rising trends for population from 1949, GDP/capita from the 1990s (when records began), fertilizer applications from 1990 (when records began), and mean annual temperature from the 1980s. In contrast, the proportion of the rural population has steadily declined since the 1980s, as has the area of cultivated land that declined rapidly in the 1960s and again in the 2000s.

The multi-decadal data for States of ecosystem services (Figure 4) clearly show two sets of broad trends. Provisioning services show generally increasing trends over the whole period starting in 1950 (grain, pigs, tea) or from the 1990s (fruit, aquatic products and timber). In contrast, regulating services show generally decreasing trends, particularly from the 1970s (soil stability-Rb/Sr ratio, air quality, water quality) and 1990s (terrestrial biodiversity) onwards. The period 1950-1980 shows stable or even improving (terrestrial biodiversity) regulating services (Figure 4).

PCA for the dataset (Figure 5) shows PC1 accounting for ~58% of the explained variance controlled by cultivated land area opposing many of the other records, especially crop yield, population, air quality (Pb), soot, tea, soil instability, fertilizers, total lake water phosphorus, fruit and pigs. PC2, with ~12% variance, shows temperature opposing precipitation, soil instability (Xfd%) and biodiversity. PCA analyses identify three clusters representing the periods 1959-1968, 1969-1993 and 1994-2006 which map onto the Great Leap Forward and the 1960s, the Cultural Revolution and early HRS period, and the later period of HRS with rural market liberation and onwards (Table 1). These three periods shift from initial associations with high levels of cultivated land and relatively low yields, to associations with climate, soil erosion and biodiversity, to the most recent associations with relatively high yields and poor air and water quality. An alternative analysis, for the 1952-2011 dataset, gives PC1 with 67.7% of the explained variance with cultivated land area opposing yield, population, pigs and yield (kg/ha). PC2 with ~11.3% explained variance shows temperature, timber, aquatics and fruit opposing precipitation. The pattern of samples shows three broad time periods dominated by 1952-1968, 1969-1996 and 1997-2011. For 1991-2011, PC1 with 51.4% of the explained variance shows cultivated land area opposing total population, temperature, aquatic, fruit, GDP and yield (kg/ha). PC2 with ~18.6% explained variance shows rural population opposing pigs and precipitation. The pattern of samples shows three broad time periods dominated by 1991-1998, 1999-2006 and 2007-2011 which more or less map onto the later period of HRS with rural market liberation, HRS grain policy and HRS subsidy policy.

Results of the breakpoint analysis for all the time-series identify (Zhang et al., 2015) abrupt changes in lake water quality in 1979 and in aggregated regulating services in 1977 broadly at the time of the early HRS. Breakpoints in provisioning service series are less clear but there is evidence for shifts during three periods: the Cultural Revolution in the mid-1960s to the early 1970s, the HRS of the late 1970s to early 1980s, and the HRS with rural market liberation in the mid-1990s.

Overall, the visual and statistical analyses of broad trends provide the following insights:

- Long term rises in provisioning services contrast with long term declines in several indicators of regulating services;
- The analyses describe a ‘land use intensification’ process involving greater provisioning of agricultural and aquatic products from a reducing farmland area involving a smaller proportion of the population, and environmental degradation through losses of soil, air and water regulating services;
- Together, these findings point to a long-term trade-off between successful agricultural production driven largely by improved farm technologies, and environmental deterioration;
- Successful agricultural production has been associated with rising total populations and total incomes (GDP/capita) even as the proportion of the rural population declines;
- Losses of ecological resilience and transgression of thresholds in natural ecosystems reached their peak during the 1970s;
- Statistically, the social-ecological system has evolved through three states seemingly determined by major national policy Responses associated with the Great Leap Forward, the Cultural Revolution and early HRS, and the later HRS with market liberation.
- The ‘early HRS’ and the later ‘HRS with market liberation’ periods are linked to abrupt changes in regulating and provisioning services that may indicate the transgression of thresholds.

Policy and social-ecological change

This section focuses on the shorter-term associations between national policy Responses and local changes in social-ecological States and Impacts. Organised by the first five phases of policy, it refers to key dates and trends (Figures 3 and 4) described in section 3.

Phase I Government control (1949-1977)

The early period of direct government control (Table 1) is notable for two major political initiatives that affected farmers: the Great Leap Forward (1958-1961) and the Cultural Revolution (1966-1976). The beginning of the Cultural Revolution maps on to the boundary between two PCA clusters in the late 1960s suggesting that the Cultural Revolution represented a major shift in the Response-Pressure-State connections within a single phase of national policy. In Shucheng, the rise in rural population after 1949 plateaued after 1955 and fell to a temporary minimum during the Great Leap Forward. This period is associated with the highest recorded cultivated land area, reduced terrestrial biodiversity and loss of soil stability (in two out of the three proxies) as the steeper marginal slopes were opened up. This is consistent with documented deforestation before the 1970s in the upper Hangbu (Dai et al., 2009) where forest area declined from 60% in the early 1950s to 27% in the mid-1970s and was associated with high levels of soil erosion. From 1964, the rural population rose again with increasing production of grains, aquatic products, tea and pigs; changes that create the first statistically significant shift in provisioning services. The following period, the Cultural Revolution, saw declining cultivated areas, recovering levels of terrestrial biodiversity, rising pig and aquatic production and seemingly increased soil stability. However, recovery of soil stability after the Great Leap Forward may be misleading because the Longhekou reservoir (built in 1958) will have trapped much of the sediment from the upper catchment. The reservoir sediment records show highest values for surface soil erosion in the mid to late 1970s (Dai et al., 2009) that coincide with the end of a seven-year period (1970–1977) in which there was a 4-fold increase in the area under tea plantations. Tea plantations are often situated on steep slopes to aid drainage, maintained with no ground cover, and liable to severe rilling. The move to increase tea plantations suggests that some land use diversification and farm income generation was occurring at the start of the Cultural Revolution before the introduction of the HRS, effectively creating a new social-ecological State. The impact of Phase I policies on farming and ecosystem services was therefore varied. It occurred largely through the direct encouragement of early deforestation of marginal mountain slopes to raise crop production but ultimately led to the expansion of tea plantations. To what extent the tea expansion was nationally directed or locally determined is not known.

Phase II Household Responsibility System (1978-1984)

The introduction of the HRS in 1978 (Table 1) is associated (Figure 3 and 4) with a constant cultivated land area, and rising tea, fruit and pig production; changes reflected in the second statistical shift in provisioning services. The steady rise in grain production since 1965 slows during Phase II with a significant drop in 1980 that coincides with a peak in the measurement of 'disaster area', possibly reflecting the lagged effect of the major drought in 1978. More certainly, the start of the period is marked by statistical shifts in water and air quality suggesting that the deforestation in Phase I coupled to the start of rural industrialisation and agricultural intensification using artificial fertilizers in Phase II had major detrimental environmental impacts. Terrestrial biodiversity fluctuates around the levels seen in the later part of Phase I but soil stability (Rb/Sr ratio) decreases further suggesting soil erosion had extended from the mountains above the reservoir to other parts of the county. Two phases of check dam building in the late 1980s (and later in Phase III) support the records for soil stability and sediment regulation services (sediment accumulation rates) that show a major decline through the late 1970s and 1980s as a result of continued accelerated erosion, despite reforestation schemes in 1976 and 1980. But overall, if Phase I was a period when policies destabilised soils and destroyed biodiversity, it seems that Phase II was the turning point towards destabilisation of air and water quality.

Phase III HRS with rural market liberalisation policy (1985-1998)

The period of 'HRS with rural market liberalisation' (Table 1) in Shucheng prior to 1997 is associated with a constant rural population and slowly increasing wealth, before a sharp increase in county GDP per capita in 1997-1998 as the rural population declines. Grain production also rises steadily from 1985 until a major decline in 1991, which is followed by a recovery and a return to just below former levels in 1998. Pig production rises steadily until the end of the period, aquatic and timber production both show sharp rises in the 1990s, but tea and fruit production show overall declines. These contrasting patterns of crop production are matched by large fluctuations in fertilizer usage. Interestingly, major statistical shifts in both provisioning services and the whole social-ecological State (Figure 5 and section 3) occur during the mid-1990s, suggesting a major change in Response-States connections within Phase III. Whatever the drivers of these changes, the ecological responses are equally diverse. One record for water quality (total organic carbon) shows rapid deterioration from the start of Phase III, but the other record (diatom-inferred total phosphorus) fluctuates about previous levels. One record for soil stability (Rb/Sr ratio) steadily declines through this period whereas the other record (magnetic susceptibility) fluctuates significantly in the period around 1990. There is strong evidence that some of the patterns in crop production and in the soil and water responses are climatically driven. The sharp drops in grain production and major fluctuations in soil stability at this time are consistent with the effects of the extreme rainfall and floods (1991-1992) and peak measurements of 'disaster areas' (1991-1995). Air quality continues to deteriorate in the first half of the phase before recovering and then falling back in the last years. Terrestrial biodiversity shows fluctuating values before falling rapidly from a peak in 1994 that parallels the rise in timber production. Overall, Phase III is typified by fluctuating patterns of crop production that may suggest a significant move towards trialling different crops or farming techniques but may also reflect the impact of extreme climate. Certainly, this phase sees the start of upward trends in the cash crops of timber, aquatic and fruit, and a gradual contraction of the area under cultivation. These agricultural changes continue to drive losses of regulating services.

Phase IV HRS with grain policy (1999-2003)

The end of Phase III is characterised by a fall in the rural population that stabilises in Phase IV, the period of 'HRS with grain' policy (Table 1). Cultivated land area falls, grain production fluctuates, grain productivity increases and fertilizer usage rises sharply before falling indicating that more marginal land was abandoned. Meanwhile tea plantations show a steady rise for the first time in ~15 years, and pig, fruit and aquatic production show continuations of the rising trends that started in Phase III. This shift towards lower levels of grain production as more profitable cash crops expand may explain the slow but steady growth in county GDP per capita. But some of the fluctuations in the grain data may also reflect the negative effects on agriculture by the major floods of 2002-03, which are marked by peak values for measured 'disaster area'. Data for timber production drops during this period and this may be reflected in the recovery in the records of terrestrial biodiversity. Records of soil stability show evidence for a long-term recovery (in two of the three proxy records) with an upturn in one of the records (Rb/Sr ratio). Water quality records now show rapidly declining signals possibly responding to the high levels of fertilizer usage. Out of all the regulating services, only air quality records show evidence for stabilised or constant conditions. Overall, Phase IV describes a contracting agricultural area, shifts in the choice of crop production, the highest recorded fertilizer usage and significant negative impacts on water quality.

Phase V HRS with subsidy policy (2004-2011)

The introduction of an 'HRS with subsidy' policy in Phase V (Table 1) is associated with increasing size of cultivated land area, increasing rural population, increased tea plantation area, increased fertilizer usage, rising grain yields and productivity, rising aquatic and timber production, but steadily declining pig production. The main impacts on regulating services until 2006 (when records end) are further declines in soil stability, biodiversity and water quality. Water monitoring data (lake Chaohu) between 2003-2010 show relatively high but fluctuating values for total nitrogen and chemical oxygen demand, but rising values for total phosphorus that confirm the long term downward trajectory for water quality. Overall, Phase V shows the impetus to the rural population and crop production induced by subsidies, with the associated losses of soil stability and water quality services.

Farmers' views

This section describes the results of a farmer questionnaire analysis.

Farm status

The farms in the survey are small with an average area of 0.44 ±0.68 ha (maximum 3.63 ha) supporting on average 3.7 ± 2.2 persons. Mountain farms are on average 38% smaller in area than the farms on the plain. The main crops are rice, wheat, cotton, rapeseed oil crops and maize (22%) (Figure 6a) with less rice and more maize grown in the mountains. The farmers are typically middle-aged to old, with a mean age of 52 ±15 years and modal peak 60-64 years, having worked on the same farm for 23 ±15 years (maximum 40 years). Around 70%

have been educated only to primary school level. Only 19% stated that farming was their main source of income, and 93% have family members working in the town. Non-agricultural income (as % of their total income) is on average 77% ± 18%. Current government subsidies received by the farmers range from zero to 6600 Yuan/yr (~1090 USD) with an average 597 ±1106 Yuan/yr (~100 ± 180 USD) largely determined by the farm size. Subsidies to the mountain farms are on average 60% lower.

Views on farming

In general, the farmers' views on agricultural management are consistent across the groups from the mountains and plains. Not surprisingly, the overwhelming majority want to maximise profit and minimise risk. Over 90% of farmers are interested in how national agricultural policies and subsidy schemes apply to their farms, and a similar percentage keep track of market prices. A majority (71%) would like to try out new agricultural ideas, like organic or precision farming, but a larger majority (90%) think they lack the appropriate knowledge. Many farmers believe that resources for new methods are unavailable to them and are generally unprepared to invest time and money in new crops and equipment. It should be noted that there is a tendency for these attitudes to differ between the sub-groups. Farmers on the plain are the least convinced that extra resources are available but are more prepared to invest their own resources. They are also less inclined to change the land use when market prices change. Overall, a majority of all farmers (69%) do not believe that the government offers opportunities for improving farm profits. It seems that the largest influences on an individual farmer is the success of nearby farms. More than 75% of farmers would copy a neighbour's new activity if they saw that it was successful.

Views on ecological degradation

The farmers rank water quality, drought and soil quality as the most important types of ecological degradation and losses of regulating services (Figure 6b). But there are differences in the sub-groups, with mountain farmers ranking drought and rivers running dry the highest, and the farmers on the plain ranking water quality and soil quality the highest. Only 8% stated that there was no degradation. The whole group varies in identifying the main causes of degradation as chemical fertilizer and pesticide use (Figure 5c), climate change, over-cultivation, new crops/techniques and deforestation, with farmers on the plain emphasising the importance of fertilizer and pesticides compared to the mountain farmers. Off-record discussions with farmers revealed a dominant view that the responsibility for the degradation lies with the government, not with farmers themselves. In the year preceding the survey, ~60% of farmers stated that they had lost income (mean loss 11%) through an environmental factor such as crop pests, drought, typhoon winds and flooding. Overall, farmers identify the start of ecological degradation (Figure 5d) with the early 2000s (Phase IV HRS with grain), as opposed to the mid-2000s or before 2000. A higher proportion of the plain's farmers give the early 2000s as the starting date compared to mountain farmers.

Plans for the future

Around 50% of farmers state that urbanisation is a major factor limiting future agricultural development and rural incomes (Figure 5e). The next ranked factor is the cost of fertilizer and pesticides while other factors relate to global food prices, ecological degradation, the role of government and insufficient land. Higher proportions of mountain farmers identified urbanisation, the role of government and insufficient land as major limiting factors, while higher proportions of farmers on the plain identified the costs of fertilizer and pesticides and ecological degradation. Regarding future intentions, farmers are fairly evenly split (Figure 5f) between planning to rent out the land, giving the land to family or others, and having no strong plans or even abandoning the farm. Mountain farmers are less certain while farmers on the plain are more likely to consider renting out their land.

Discussion

"China's transition to sustainability should take advantage of its ability to implement massive programs that can infiltrate every aspect of society rapidly" (Liu, 2010 p. 50)

Over the 65 year-long period, farmers and the environment have responded directly and indirectly to the general trend of liberalisation, a trajectory buoyed by rising population, demands and incomes. The generally rising trends in provisioning services (Figure 5) reflect the farmers' increased profit motivation and steadily rising personal wealth that allows for improvements in the use of hybrid crops, mechanisation, fertilizer and pesticides: a process of 'land use intensification'. In contrast, there are parallel long-term losses or degradation of some regulating services, notably soil stability, air quality and water quality (Figure 4). These divergent trends constitute a long-term trade-off for food and income against environmental quality; a socially and politically acceptable trade-off that has strengthened each decade since the 1980s.

In terms of FESP, the strongest links within the social-ecological system (Figure 2) have been processes operating in the States component, specifically the Adaptation by farmers to successive national policy Response decisions aimed at liberalisation, increasing the Service Provision of agricultural goods through intensification. This has driven investment in technologies and fertilizers, and subsequent incomes, which has created a positive feedback loop. As the positive loop has strengthened, the Impacts on Service Provision have been positive for provisioning services and largely negative for regulating services. However, there remains a disconnect by government of the link between Impacts on all Services Provision and States through Response policies that Adapt to Trade-offs and Valuation of Services. Even though there is clear evidence for Trade-offs between provisioning and regulating service provision, the Responses in terms of national policy have largely been through Mitigation effects on economic Drivers and land use Pressures than through Adaption in terms of direct environmental protection. For example, the Phase IV 'HRS with grain' marketization policy period saw a shift away from grain cropping with a sharp drop in total grain yield as farmers chose cash crops over grains. This is reflected in a slowing down in water quality degradation and possibly some recovery in biodiversity and soil erosion (Figure 4) temporarily suspending the trade-off, but only as an indirect result of policy Responses affecting economic Drivers. The change in policy Response during the following Phase V 'HRS with subsidy' period (Figure 3), when grain crops were 'made' more profitable to counter declining crop yields, shows the direct link between Impacts on Service Provision, Valuation of Services and Responses. Within two years, fertilizer usage and grain yields renewed their long-term rise and, as a result, water quality degradation accelerated and there is some evidence for declining levels of soil stability and terrestrial biodiversity (Figure 4). As the subsidy system became established, the levels of county GDP per capita grew at an unprecedented rate. The evidence suggests that during these phases the government and farmers responded rapidly to each other's decision-making rather than the State of the environment.

In terms of the effects of Drivers and Pressures on the States, the strongest direct evidence is in terms of the short-term, rather than long-term impacts of weather events on crop yields. But overall, the strongest effects of Responses on exogenous Drivers and Pressures has been through national economic growth, and especially urbanisation within rural areas, that will have strengthened the Shucheng farming system through increasing market demand for crops and providing additional sources of family income. Farmers have acted primarily as Ecosystem Service Providers and do not appear to have influenced, or been strongly influenced by, national policy Responses that directly address Impacts on regulating services. This despite the widely held views of farmers that environmental protection and restoration are the government's responsibility.

The question now is whether the nature of the trade-off is changing to one where continued and successful exploitation of provisioning services is directly undermined by a decline in regulating (and supporting) services. The long-term declines in soil stability and, especially, in water quality reflect the gradual losses in ecological resilience, with the sharp downward declines in water quality in the 1970s and at the end of the 'HRS with grain policy' period indicative of critical transitions from one steady state to another (Zhang et al., 2015). These declines could be caused by long-term positive feedback loops, such as adding artificial fertilizers to gain year-on-year productivity gains while natural soil fertility (encompassing organic matter, soil structure and soil depth) continually deteriorates from over-cultivation. However, there is no direct evidence that the trade-offs over several decades significantly constrained provisioning services (although the shift in downstream lake water quality will likely impact lake fisheries). For example, the fluctuating and low grain yields between 1989-2004 seem to be less the result of biophysical constraints and more the combined effects of inefficient grain production before subsidies were introduced, and extreme climate impacts. Only the last two years of grain yields (2010 and 2011) that show the first downturn since 2001 could indicate a long-term cumulative and negative impact on crop productivity: the corollary to the environmentalist's paradox (Raudsepp-Hearne et al., 2010).

Even if ecological degradation is currently insufficient to reduce crop productivity, there is strong evidence that the state of soil, fluvial and lake systems in Shucheng may be shifting (or in the case of lakes have already shifted) to undesirable states (Zhang et al., 2015). The majority of farmers questioned were aware of the changes in provisioning and regulating services shown in this study, at least since Phase III. They identified water quality as the most degraded regulating service, especially those living on the plain, and to some extent soil quality, with fertilizers and pesticides as the main causes of degradation. Interestingly, changes in the local climate were also identified, especially from the mountain farmers whose livelihoods are sensitive to drought and rivers drying up, which is consistent with the PCA evidence for associations with precipitation in the 1980s (Figure 5) and records of extreme climate events impacting on crop production and soil stability, especially since the 1990s when mean temperatures began to rise (Figure 3). Less consistent with the biophysical records are the farmers' perceptions of when the ecological degradation began, which they generally identify as the period since the mid-2000s. This period includes a sharp decline in water quality but significantly underestimates the long-term declines in water quality, air quality and soil stability that started around the time the HRS was introduced in the 1980s (Figure 4).

What are the implications for designing and implementing new policies over the next five to thirty years? In order to address the losses of regulating services, farming has to become more efficient with respect to the use of soil, water, pesticides and fertilizers. Successful Land Circulation could bring more mechanisation of manual processes, leading to more efficient delivery of seed, fertilizer and pesticide, and importantly produce rental incomes for absent farmers. However, as observed elsewhere in China (Du & Bo, 2011; Chen & Du, 2014), Shucheng farmers are uncertain about what should happen to their farms with 35% having no strong plans. Even on the plains only 45% of farmers are considering the Land Circulation option and, in the mountains, where field sizes are mainly constrained by topography, farmers are even less keen. It follows that urgent delivery of scientific and place-based practical advice and guidance directly to farmers is crucial to the success of any current or future land management policy (Cui et al., 2018). This all points strongly to a need for a significantly improved system of information and technology transfer, probably involving a more efficient coordination between agencies. Agriculture Technology Extension Centres exist but many of the personnel are not qualified to give up-to-date advice (Zhang Weijian personal communication) and increasingly focus on farm organisation issues and sales. In selected counties, the Science and Technology Backyard programme (Zhang et al., 2016) that promotes agricultural scientists living in villages among farmers shows encouraging results with respect fertilizer management, irrigation and crop yields. But generally, there is a major gap between making policy Responses at the national level and implementing the appropriate practices for Adaptation at the local level.

The Opening-Up Reforms in the late 1970s set Chinese agriculture on a path that has tracked the national rising level of wealth: a path-dependent union between agricultural intensification, poverty alleviation and ecological degradation. Where Shucheng differs from the average county is in the overall lower income levels that are partly due to the marginal nature of farmland in the mountains. Nevertheless, our study is perhaps representative of the hundreds of agricultural communities in marginal landscapes across China, supporting millions of people, but which lag behind the general economic growth. These communities may not engage in the most intensive agriculture but a long history of poor practices may still jeopardise the long-term sustainability of ecosystem services in these areas. The urban lure of higher incomes is possibly stronger than in wealthier communities making the viability of land tenure reforms, the transfer of information and technology, and succession of the family farm far less certain as young people reject farming as a livelihood. As the current farmers retire over the next 10-15 years, the issue of low farm incomes is likely to become pivotal in any debate about sustainable agriculture in China.

Conclusions

- Shucheng represents a policy-responsive farming community that has driven up levels of crop productivity. This has led to long-term ecological degradation, a situation viewed (in 2012) as an acceptable trade-off. Individual bottom-up actions framed by top-down national policy and embedded in contemporary agricultural culture have led to continuing losses of regulating services that reduce the resilience of the agricultural system and threaten to undermine crop yields in the future. Neither the farmers nor the state has directly determined the trade-off. It is more an emergent feature of farmers adapting to a long-term policy of liberalisation playing out over multi-decadal timescales.

- In general, farmers have been highly responsive to policies that drive positive feedback loops by developing and exploiting provisioning services according to levels of profits and subsidies that, in turn, raise incomes. The periods of 'HRS with grain' and 'HRS with subsidy' demonstrate the negative and positive effects of policy on farmers, as shown by fluctuating crop yields. The relationship between poverty alleviation and ecosystem services has been coupled strongly through provisioning services and less through regulating services. Indeed, the liberalisation process that has led farmers to improve agricultural productivity and their own wellbeing has not led to a stronger sense of stewardship over the environment.

- Farmers identify correctly the main types of long-term ecological degradation and the proximate causes. But they perceive the start of the degradation significantly later than the scientific evidence. The results show that the extent of degradation is only realised after rapid declines: otherwise masked by the process of ‘creeping normalcy’. Water quality has deteriorated most rapidly and there is evidence that critical thresholds may have been passed in downstream lake ecosystems. Extreme climate events can deliver direct impacts on both provisioning and regulating services and there is evidence that the long-term warming trend may also have an impact on services. The long-term rates of decline in regulating services are unsustainable but in the absence of relevant policy farmers show little motivation to make restorative actions.

- Unfortunately, urbanisation, low farm incomes, low educational attainment levels and an aging demographic still represent barriers to viable farming. Incomes from farm produce and government subsidies are still low, and insufficient to maintain a farming family whose head is normally middle-aged or close to retirement. Together with the lack of information transfer and technology, today’s farmers are not in a strong position to make changes that would simultaneously produce step-changes in income and reverse the negative ecological trends. Land Circulation, designed to overcome inefficient farm sizes, may not be taken up widely.

- The similarities between the long-term trends observed at Shucheng and other rural counties in eastern China (e.g. Zhang et al., 2015) indicate that the findings may apply more broadly. This indicates that maintaining or increasing current productivity levels while simultaneously slowing or reversing the losses of regulating services nationally requires new national or regional policies that promote bottom-up, restorative influences on the environment and a sense of stewardship within an inter-generational strategy for farm land use and management. Future national policies need to embrace systems perspectives and focus on delivering scientific and place-based information and technology to farmers through environmental advisors.

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Declaration of interest statement

None of the authors has any relevant interests to disclose.

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Appendix

Questionnaire survey

Farmer Characteristics:

1. How long have you lived on and farmed this land? ______________________________________
2. How old are you? __________
3. What is your education level? ____
4. How many people are supported by (or are dependent on) this farm? ________________________
5. What relation are these people to you? (e.g. spouse, children (adult or child), other family, workers, other)
   ____
6. Do you own, rent or manage this land? (please specify) __________________________________
7. How much land does this farm cover? ____
8. What is the land currently used for? Please give land-use type and approximate area (e.g. crops (please specify), grass/hay, trees, for livestock, fallow, industry, other)?

Land use type	Area
____	_________________
____	_________________
____	_________________
____	_________________

9. What farm equipment do you have access to? (include those you can rent) ____________________
   ____
10. Do you sell crops/livestock/timber and their products for profit? ____________________________
    a. If so, who do you sell to (e.g. neighbours, local market, co-op, commercial buying agent, food processing, etc.)?
       ____
11. Do you and your household have any non-agricultural income generating activities? If so:
    a. What are these? ____
    b. About how many hours a week do you (or other members of your household) spend on these activities?
       ____
    c. Does this income contribute significantly to that from the farm? ______________________

Land-Use Change:

12. Have you changed the land use of any part of your farm, or bought/sold land, in the last 10 years? __
13. If so, what did the land use change from and to? ____
    ____
    ____
    ____
    _
14. Why did you make this change? (please tick all that apply)
    - ☐ To make more money
    - ☐ Previous land-use became uneconomic
    - ☐ Changes in yield or productivity of land
    - ☐ Changes in water availability/ climate/weather
    - ☐ Took an opportunity to try new crop/technology/enterprise
    - ☐ My neighbours tried this
    - ☐ Suggested by family or friends
    - ☐ To minimise risk
    - ☐ Lack of labour, time or other resources please state______________________
    - ☐ Changes in subsidies or market prices
    - ☐ Incentives or initiatives from local/national government or EU
    - ☐ To maintain or improve the quality of the land
    - ☐ Other, please specify ______________
      ____
15. What will happen to this farm when you retire? ____

Environmental issues:

16. Which part of environment do you think is degrading most seriously? (   )
A. Forests B. Air pollution C. Water quality D. Flooding E. Drought F. Soil erosion
G. Soil quality H. Biodiversity loss I. Others (please specify)

18. What do you think has caused the degradation? (   )
A. Fertilizer usage B. Climate change C. Deforestation D. Land use change
E. Industrialization F. Others (please specify)

19. When do you think the degradation started? (   )
A. 5 years ago B. 10 years ago C. 20 years ago D. 30 years ago

20. Did natural disasters or other environmental problems cause you to lose money last year? If yes,

What are the reasons ( ), and how much do you lost ( ), and what is the percentage it accounting for your total annual income? ( )

21. Which part of natural environment is more important to you, please rank them from 1 to 5, 1 represent less important and 5 represent most important.
Soil erosion ( ) Water pollution ( ) Biodiversity loss ( ) Air pollution ( )

22. Where do your agricultural skills come from? ( )
A. Previous generation B. Labouring experience C. Advisor D. Others (please specify)

23. Do you have idle land? If yes, why? ( )
A. Land quality degradation B. Lack of labour C. Agricultural price is too low
D. too far from home E. Others (please specify)

24. What kind of subsidies did you receive last year, and how much were they worth?

25. What factor do you think limits the agricultural development and rural income in this area? ( )
A. Environment degradation B. Urbanization C. Policy D. Global food price E. Others (please specify)

26. To what extent do you agree or disagree with the following statements:	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
I change the land use frequently				
I want to maximise my profit				
I want to minimise risk				
I would like this farm to stay in the family				
I want to maintain traditional farming methods				
I am concerned that new people moving into the area will ruin its character				
I watch what my neighbours are doing with their land				
If I see my neighbours are doing well with a new farm method or activity, I would try it too				
I would like to try out new agricultural methods and activities				
I am not interested in new ideas and schemes, e.g. organic farming, agricultural environmental management, precision farming				
I feel that I lack the knowledge to try new farming methods and activities				
I would like to research new farming methods and activities				
I believe that I can get the resources to try new farming methods and activities				
I am prepared to invest time and money in new farm equipment, methods or crops				
I am interested in national agricultural policies and subsidies and how they apply to my farm				
I keep track of market prices				
I will change my land use if market prices change significantly				
I try to anticipate changes in the market				
I am not interested in agricultural policies and subsidies and how they apply to my farm				
I think that government offers opportunities for improving farm profits in this area				
I will change land use if physical farming conditions change				

Please use this space for any information you didn't have space for earlier.

Figures

Figure captions

Figure 1. Shucheng County, lake Chaohu and the surveyed towns in the Chaohu catchment (inset shows location in eastern China).

Figure 2. A Framework for Ecosystem Service Provision based on a modified Driver-Pressure-State- Impact-Response framework (Rounsevell et al., 2009).

Figure 3. Drivers, Pressures and Impacts on Shucheng county 1950-2010: a) Total population, GDP/capita and population working in agriculture (%); b) annual mean temperature (^{o}C), annual precipitation (mm) and climate-related disasters measured as 'disaster area' (km^2); c) cultivated land area (km^2), tea garden area (km^2), and Anhui fertilizer usage (10^5 t).

Figure 4. States of ecosystem services in Shucheng county 1950-2010: a) normalised provisioning services – total grain yield, pigs, fruit, tea, aquatic products, and timber; b) normalised soil stability and sediment regulation regulating services – sediment magnetic susceptibility, sediment accumulation rates and Rb/Sr geochemical ratio; c) normalised air quality regulating services – sediment Pb and soot concentrations; d) normalised water quality regulating services – diatom-inferred total phosphorus (DI-TP) and sediment total organic carbon (TOC) - with monitoring records (mg L^{-1}) of total phosphorus (TP), total nitrogen (TN) and chemical oxygen demand (COD); e) normalised biodiversity – rarefaction index of terrestrial pollen taxa. Vertical dashed lines delineate agricultural policy Phases I-V where HRS abbreviates Household Responsibility System (Table 1) and grey vertical bars show Great Leap Forward and Cultural Revolution.

Figure 5. Biplot of the Principal Component Analysis of the Shucheng data from 1959-2006 showing the first (PC1; ~58% of the variance) and second (PC2; ~12% of the variance) principal components for each year and the variables within the correlation circle. Three clusters can be clearly delineated, representing a) the Great Leap Forward and the early 1960s

(red), b) the Cultural Revolution and the early Household Responsibility System (green), and c) the Household Responsibility System and market liberalisation (blue). The variables are labelled as: Pop.Tot. (Total Population), Pop.Rur. (Rural Population), Tmp. (Temperature), Prcp. (Precipitation), Tmp.Hei. (Temperature in Heifi), Prcp.Hei. (Precipitation in Heifi), TeaGard (Tea Garden Area), Fert.Anh. (Fertiliser Usage in Anhui), Cultv. (Cultivated Area), Yield.t (Total Grain Yield), Yield.kgha (Grain Yield per hectare), Pigs, Fruit, Tea, Aquatic (Aquatic Products), Timber, Biodiv (Biodiversity), SoilStab.Xfd (Soil Stability by Xfd), SoilStab.RbSr (Soil Stability by Rb/Sr), Sed Reg (Sediment Regulation by MAR), Air (Air Quality by Lead), Soot (Air Quality by Soot), DITP (Water Quality from DI-TP), TOC, Sed (Sediment Quality).

Figure 6. Farmers' questionnaire responses: a) crops grown; b) main types of ecological degradation; c) causes of ecological degradation; d) start date of ecological degradation; e) barriers or threats to farming; f) personal plans for the future. Data plotted with highest 'total' responses to the left, where 'total' data refers to responses by all farmers (n=68), and 'plains' and 'mountains' refer to subsets of respondents farming the lowlands (n=35) and (n=33) hilly lands respectively. Percentage data in a), b), c) and f) do not add to 100% because farmers were free to choose more than one answer.

Who determines the trade-offs between agricultural production and environmental quality? An evolutionary perspective from rural eastern China.

Abstract

We explore the evolutionary nature of interactions between government policy, farm decision-making and ecosystem services in Shucheng County, Anhui Province from 1950 to 2015. Analyses of ecological, social and economic trends are complemented by interviews with local farmers about their status, perceptions and attitudes. Since the introduction of the Household Responsibility System in 1980, the start of liberalisation, there has been a trade-off between rising levels of provisioning services and falling levels of regulating services in the environment, with some evidence that critical thresholds have been passed for water quality. Using a Framework for Ecosystem Service Provision, we argue that farmers have acted only as ecosystem service providers and have not influenced the national/regional policies that have brought about the trade-offs. Over the whole period, ecological degradation is best described as an example of 'creeping normalcy' where cumulative conventional actions by individual farmers produce unsustainable losses in regulating services. The Chinese government should be acting to balance the various ecosystem services through valuation and national policy. In this respect, there is a need for a new coordination of agencies that can deliver scientific and place-based advice to farmers that will allow them to maintain productivity levels while pursuing restorative actions. Even with new policies, the draw of urban employment and high production costs threaten the viability of farming in these marginal agricultural areas, especially over the next 10-15 years when most current farmers will retire.

Keywords: China; social-ecological systems, ecosystem services; evolutionary frameworks; trade-offs.

Introduction

Warnings about the possible long term negative consequences of unsustainable farm practises (Raudsepp-Hearne et al., 2010) are partly borne out by global figures that show widespread stagnation and declines in grain yields (Mehrabi et al., 2019; Ray et al., 2012). However, the whole process through which agriculture is deemed to lie on a sustainable trajectory or not is complex. Sustainable agriculture depends not only on current top-down government policy and resource management strategies (Foley et al., 2011) but also on bottom-up decisions made by farmers in the light of national policy, markets and their knowledge about the environment (Duong et al., 2019; Fairweather et al., 2008). Farmers make decisions in response to less predictable short-term factors (Darnhofer et al., 2011), such as extreme climate events and energy costs, as well as to the likely impact of longer term trends, such as the emphasis in many countries on increasing crop yields through agricultural intensification (Garnett et al., 2013; Poppy et al., 2014; Pretty et al., 2018). In these ways, agriculture may be viewed as a complex system of ecosystem services with exogenous and endogenous drivers and pressures working through feedback mechanisms over a variety of timescales (Armstrong McKay et al., 2019; Zhang et al., 2018).

In the People's Republic of China, agricultural output in the period 1950-2015 rose five-fold (Li et al., 2013). This has been achieved through technological advances, including new high yielding crops, mechanisation, fertilizers, pesticides and irrigation. In addition, policy reforms have moved farming away from collective systems towards more independent commercial regimes. Government policies since 1979 mainly reflect two sets of concern: maintaining or increasing crop yields, particularly grains, and reducing the incidence of hazards, like flooding and soil erosion. In ecosystem service terms, these different motivations have focused on extracting provisioning goods and services, and on protecting regulating services respectively. However, despite efforts to protect the environment, the growth in production has been linked to widespread ecological degradation, particularly soil erosion, salinisation, desertification and water pollution (Liu & Diamond, 2005).

Our recent studies have highlighted the long-term trade-off between growing provisioning services and declining regulating services within the lower Yangtze basin (Dearing et al., 2012a; Lin et al., 2019; Zhang et al., 2015), and the widespread irreversibility of environmental degradation across China (Zhang et al., 2016). Indeed, a major challenge for Chinese agriculture is to find ways of maintaining or growing outputs while stabilising or reducing the ecological impacts. Chen & Du (2014) suggest that the socio-economic constraints could be reduced with economic development and changes in land tenure and land management. But to do this requires more detailed information about how past policies and reforms have affected the social-ecological systems in rural China.

Here we focus on one of those areas in the lower Yangtze basin, Shucheng County (hereafter Shucheng) in order to try and understand how trade-offs between rising production and deteriorating environmental quality have reflected the interaction of national agricultural policy and local farming decisions. Shucheng is an agriculturally marginal 'poverty-stricken' county with low levels of income, offering a chance to observe the environmental constraints on long term economic growth and poverty alleviation, and the possible negative consequences of environmental degradation. We have designed a research methodology that addresses the following overarching questions:

- How have national policies affected farming decisions and ecosystem services through time?

- Were local farmers able to perceive the environmental degradation and make restorative actions?

- Given the findings, what are the implications for designing or implementing appropriate policies over the next thirty years?

Materials and Methods

Shucheng County

Shucheng (area 2092 km^2) lies to the west of Chaohu lake in Anhui Province (Figure 1). The landscape of the county comprises the Dabie Mountains (52% area) in the west, a central hilly area (20% area), and alluvial plains (28% area) extending to the lake edge. The population of the county doubled between 1950 and 2000, from 489 500 to 983 379 (Chorography Compilation Committee of Shucheng County, 1995; Yan et al., 2009), and is currently ~1 million with 86% engaged in agriculture. As a result of reforestation since the 1960s, the total area under cultivation decreased from 507 km^2 (1950) to 416 km^2 (2009). The Green for Grain Programme (1999-2007) gave payments across China for ecosystem services in order to convert croplands on steep slopes to forest (Liu et al., 2014). Main crops are rice, wheat, cotton and rapeseed in the plains with rice, tea and chestnuts in the mountains, and vegetables near major towns. Labelled by the national government as one of the ~590 ‘poverty-stricken’ counties of China, an annual farmer’s income was (in 2008) approximately US$ 900. Despite reforestation of up to 65% of the steep slopes in Shucheng (Yuan et al., 2014; Yu, 2011;

Zhang et al., 2010), soil erosion, river sedimentation, flooding and water pollution have at various times become serious problems (Dai et al., 2009), undermining poverty reduction activities and sustainable rural development.

Chinese agricultural policy 1949-2011

Since 1949, farmers in Shucheng, as in every Chinese county, have worked under the direct influence of national agricultural policy. Li et al. (2013) define six historical phases of national agricultural policy aimed at influencing grain production. From Phase I (1949-1977) to Phase VI (2011 onwards) there was a shift of direct control and responsibility from the government to the household. Phase I was a collectivised economy where farmers were given quotas for food production but no extra compensation for producing beyond the quota. The introduction of the Household Responsibility System (HRS) at the beginning of Phase II in 1978 reallocated land rights from the People's collectives to individual farms with the opportunity for farmers to sell surplus produce at a market price. During Phase II, farmers' quotas were reduced which gave further incentives to produce crops for sale at market prices. Phase III extended the liberalisation process with promotion of pesticides and fertilizers and non-grain cash crops through price controls. Phase IV (1999-2003) saw a drop in national grain production as farmers shifted their focus towards cash crops in response to the government leaving grain prices to be controlled by the market. In order to restore grain production, in 2004, the government removed agricultural tax and introduced subsidies for grain production (Phase V). Although national figures for grain production have been revived by these measures the rates of increase since then (Phase VI) are low relative to the large inputs of fertilizer and other resources (Li et al., 2013). The ongoing response to 'inefficient farming' is the reform of land management through Land Circulation (Li, 2010) involving aggregation of small fields into larger units that is designed to improve the economies of scale and incomes.

Some national fluctuations in historical grain production figures are therefore explained by changes in national policy (Xu et al., 2014). However, since 2000, there have been notable short- term fluctuations in annual yields that have led to speculation that agricultural production in some regions is now biophysically constrained by resource depletion, such as groundwater (Brown, 2013) or positive feedback mechanisms, like soil acidification (e.g. Guo et al., 2010). Other commentators (e.g. Li et al., 2013) argue that the slow increase in grain production in recent years is due to the lack of modern agricultural technology and methods. Indeed, results from field experiments across China (Chen et al., 2014) suggest that current yields of rice, wheat and maize could be raised by 18-35% through the adoption of integrated soil-crop system management practices though the results of a major field campaign trial puts these figures at a lower level, at about 11% (Cui et al., 2018).

Study approach

We take an evolutionary approach (Dearing et al., 2012b) that combines information on changes in national policy, farm activities and ecosystem processes over 65 years together with the views of current farmers. An evolutionary perspective is important for identifying the timescales of drivers, ecosystem states and human responses, understanding the nature of trade-offs between ecosystem services, and evaluating the extent to which a social-ecological system is contingent on past events and conditions, or even path-dependent. Such information can also help identify whether detrimental transitions (tipping points) in, for example, productivity or ecological states, have already occurred or inform on the likelihood of thresholds being transgressed in the near future. Transitions are often relatively rapid but may be the culmination of slow incremental change in some key process that are imperceptible without long term ecological monitoring (Zhang et al., 2007; Zhang et al. 2015), and may be costly to fix or even irreversible (Scheffer et al., 2012). In order to facilitate analyses, we embed the evolutionary approach within a Framework for Ecosystem Service Provision (FESP - Rounsevell et al., 2009) based on a modified Driver-Pressure-State-Impact-Response[1] (DPSIR) framework (Figure 1). The FESP integrates across multiple services and scales, makes explicit the exogeneous and endogenous drivers within the system, and, importantly, allows for feedback mechanisms that drive non-linear interactions.

Annual statistics for agriculture, population, economy and climate are available at provincial (1949-2008) and county levels (~1980s to 2008) giving time-series for provisioning ecosystem services and socio-economic-environmental drivers, but ecological monitoring of water quality and other ecological processes are, at best, available for recent years only. Regulating services are the most important in terms of determining the sustainability of land systems but are often poorly understood or under-represented in studies because of insufficient data. Therefore, we use laboratory analyses of lake sediments to allow the novel historical reconstruction of multi-decadal trends in major regulating ecological services within the upstream catchment and lake (Dearing et al., 2012a). Here, we use dated sediment cores sampled from Chaohu lake as proxies for decadal time-series of water quality, lake productivity, air quality, sediment quality, terrestrial biodiversity and soil stability.

We first describe the multi-decadal trends and use principal component analysis (PCA) and breakpoint analyses to reveal plausible long-term associations between Drivers, Pressures, States and Impacts (Figure 2). Second, we compare the temporal data against shorter term policy changes to tease out plausible links between Responses (policy decisions), Pressures,

[1] Throughout the text we capitalize the first letter of terms referenced within the FESP.

Impacts and States. Third, we interrogate the links between human behaviour and ecosystem services within States and Impacts through the results of a questionnaire survey, exploring how changes in ecosystem services are perceived by local farmers, how they currently assess their farming in terms of policy and income, and how they are planning for the future. Finally, we draw the findings together in addressing the research questions.

Time-series data and statistical analyses

Official annual statistical data for social, economic and agricultural changes were obtained for Shucheng, Anhui Province, and an average for of all China's Provinces from Statistical Year Books. Climate data were obtained from monitoring records in the nearby Hefei City located 50 km to the northeast of Shucheng (Figure 1). Sediment data were obtained (see Dearing et al. 2012a for full details) from sediment cores taken from the western side of Chaohu with a piston corer in 2006. Core sediments were subsampled at a 0.5 cm resolution for 0–50 cm and 1 cm resolution in deeper sediments. Sediment samples were dated using ^{210}Pb and ^{137}Cs radioisotopes, and a constant rate of supply model was used to calculate a chronology and depth-age curves for each core. Only data in the period ~1950-2006 are used in the present study. Typically, the dating errors are ±5 years (2 st. dev) for 1950 reducing to ±2 years in recent years. The sediments were analysed to produce the following proxies for ecosystem services:

- Sediment regulation proxy: dry mass sediment accumulation rates (SAR)
- Soil stability proxies: magnetic susceptibility and the Sr/Rb geochemical ratio.
- Air quality proxies: lead (Pb) and soot concentrations.
- Water quality proxies: diatom inferred-total phosphorus and total organic carbon (TOC).
- Biodiversity proxy: rarefaction indices for floristic richness in pollen counts.

Normalised data varying between 0 and 1 are used (Figure 3) so that trends can be easily compared and aggregated. The formula used for scaling the data series (x1:xn) to (0:1) is x1-(min x1:xn)/[(max x1:xn)-(min x1:xn)] where min and max are minimum and maximum values within the data range. In the case of biodiversity, values of 1 and 0 equate to highest and lowest levels of ecosystem service. For all other proxy records, like soil stability, values in the range 1 to 0 were inverted so that values of 1 and 0 equate to highest and lowest levels of ecosystem service respectively. Principal components analysis of the time-series data was performed and plotted by the *prcomp* and *ggbiplot* functions in R (R Core Team, 2017). Statistically significant ($p \leq 0.01$) breakpoints in time-series were calculated (Zhang et al., 2015) as evidence for shifts in system or sub-system states.

Questionnaires and focus groups

A questionnaire with closed and open questions was designed (see Appendix) to obtain information about current farming activities, farmer's perceptions of ecological degradation and their future plans. Farmers were selected randomly from towns situated in the two most contrasting landscape-farm systems across the county (Figure 2): mountains (Hepeng) and plains (Hangbu). The survey, conducted in August 2012, was administered to 68 farmers (33 from Hepeng and 35 from Hangbu). Trained university research students conducted face-to-face interviews with farmers at their house or at local agricultural offices, where interviews typically lasted 30 minutes. All the interviews were conducted on a voluntary basis, and farmers consented verbally to a written set of survey aims and the anonymous use of the collected data.

Results

Trends and statistical analyses

Trends for the main Drivers, Pressures and Impacts within the system show (Figure 3) rising trends for population from 1949, GDP/capita from the 1990s (when records began), fertilizer applications from 1990 (when records began), and mean annual temperature from the 1980s. In contrast, the proportion of the rural population has steadily declined since the 1980s, as has the area of cultivated land that declined rapidly in the 1960s and again in the 2000s.

The multi-decadal data for States of ecosystem services (Figure 4) clearly show two sets of broad trends. Provisioning services show generally increasing trends over the whole period starting in 1950 (grain, pigs, tea) or from the 1990s (fruit, aquatic products and timber). In contrast, regulating services show generally decreasing trends, particularly from the 1970s (soil stability-Rb/Sr ratio, air quality, water quality) and 1990s (terrestrial biodiversity) onwards. The period 1950-1980 shows stable or even improving (terrestrial biodiversity) regulating services (Figure 4).

PCA for the dataset (Figure 5) shows PC1 accounting for ~58% of the explained variance controlled by cultivated land area opposing many of the other records, especially crop yield, population, air quality (Pb), soot, tea, soil instability, fertilizers, total lake water phosphorus, fruit and pigs. PC2, with ~12% variance, shows temperature opposing precipitation, soil instability (Xfd%) and biodiversity. PCA analyses identify three clusters representing the periods 1959-1968, 1969-1993 and 1994-2006 which map onto the Great Leap Forward and the 1960s, the Cultural Revolution and early HRS period, and the later period of HRS with rural market liberation and onwards (Table 1). These three periods shift from initial associations with high levels of cultivated land and relatively low yields, to associations with climate, soil erosion and biodiversity, to the most recent associations with relatively high yields and poor air and water quality. An alternative analysis, for the 1952-2011 dataset, gives

PC1 with 67.7% of the explained variance with cultivated land area opposing yield, population, pigs and yield (kg/ha). PC2 with ~11.3% explained variance shows temperature, timber, aquatics and fruit opposing precipitation. The pattern of samples shows three broad time periods dominated by 1952-1968, 1969-1996 and 1997-2011. For 1991-2011, PC1 with 51.4% of the explained variance shows cultivated land area opposing total population, temperature, aquatic, fruit, GDP and yield (kg/ha). PC2 with ~18.6% explained variance shows rural population opposing pigs and precipitation. The pattern of samples shows three broad time periods dominated by 1991-1998, 1999-2006 and 2007-2011 which more or less map onto the later period of HRS with rural market liberation, HRS grain policy and HRS subsidy policy.

Results of the breakpoint analysis for all the time-series identify (Zhang et al., 2015) abrupt changes in lake water quality in 1979 and in aggregated regulating services in 1977 broadly at the time of the early HRS. Breakpoints in provisioning service series are less clear but there is evidence for shifts during three periods: the Cultural Revolution in the mid-1960s to the early 1970s, the HRS of the late 1970s to early 1980s, and the HRS with rural market liberation in the mid-1990s.

Overall, the visual and statistical analyses of broad trends provide the following insights:

- Long term rises in provisioning services contrast with long term declines in several indicators of regulating services;
- The analyses describe a ‘land use intensification’ process involving greater provisioning of agricultural and aquatic products from a reducing farmland area involving a smaller proportion of the population, and environmental degradation through losses of soil, air and water regulating services;

- Together, these findings point to a long-term trade-off between successful agricultural production driven largely by improved farm technologies, and environmental deterioration;
- Successful agricultural production has been associated with rising total populations and total incomes (GDP/capita) even as the proportion of the rural population declines;
- Losses of ecological resilience and transgression of thresholds in natural ecosystems reached their peak during the 1970s;
- Statistically, the social-ecological system has evolved through three states seemingly determined by major national policy Responses associated with the Great Leap Forward, the Cultural Revolution and early HRS, and the later HRS with market liberation.
- The 'early HRS' and the later 'HRS with market liberation' periods are linked to abrupt changes in regulating and provisioning services that may indicate the transgression of thresholds.

Policy and social-ecological change

This section focuses on the shorter-term associations between national policy Responses and local changes in social-ecological States and Impacts. Organised by the first five phases of policy, it refers to key dates and trends (Figures 3 and 4) described in section 3.

Phase I Government control (1949-1977)

The early period of direct government control (Table 1) is notable for two major political initiatives that affected farmers: the Great Leap Forward (1958-1961) and the Cultural Revolution (1966-1976). The beginning of the Cultural Revolution maps on to the boundary between two PCA clusters in the late 1960s suggesting that the Cultural Revolution represented a major shift in the Response-Pressure-State connections within a single phase of national policy. In Shucheng, the rise in rural population after 1949 plateaued after 1955 and fell to a temporary minimum during the Great Leap Forward. This period is associated with the highest recorded cultivated land area, reduced terrestrial biodiversity and loss of soil stability (in two out of the three proxies) as the steeper marginal slopes were opened up. This is consistent with documented deforestation before the 1970s in the upper Hangbu (Dai et al., 2009) where forest area declined from 60% in the early 1950s to 27% in the mid-1970s and was associated with high levels of soil erosion. From 1964, the rural population rose again with increasing production of grains, aquatic products, tea and pigs; changes that create the first statistically significant shift in provisioning services. The following period, the Cultural Revolution, saw declining cultivated areas, recovering levels of terrestrial biodiversity, rising pig and aquatic production and seemingly increased soil stability. However, recovery of soil stability after the Great Leap Forward may be misleading because the Longhekou reservoir (built in 1958) will have trapped much of the sediment from the upper catchment. The reservoir sediment records show highest values for surface soil erosion in the mid to late 1970s (Dai et al., 2009) that coincide with the end of a seven-year period (1970–1977) in which there was a 4-fold increase in the area under tea plantations. Tea plantations are often situated on steep slopes to aid drainage, maintained with no ground cover, and liable to severe rilling. The move to increase tea plantations suggests that some land use diversification and farm income generation was occurring at the start of the Cultural Revolution before the introduction of the HRS, effectively creating a new social-ecological State. The impact of Phase I policies on farming and ecosystem services was therefore varied. It occurred largely through the direct encouragement of early deforestation of marginal mountain slopes to raise crop production but ultimately led to the expansion of tea plantations. To what extent the tea expansion was nationally directed or locally determined is not known.

Phase II Household Responsibility System (1978-1984)

The introduction of the HRS in 1978 (Table 1) is associated (Figure 3 and 4) with a constant cultivated land area, and rising tea, fruit and pig production; changes reflected in the second statistical shift in provisioning services. The steady rise in grain production since 1965 slows during Phase II with a significant drop in 1980 that coincides with a peak in the measurement of 'disaster area', possibly reflecting the lagged effect of the major drought in 1978. More certainly, the start of the period is marked by statistical shifts in water and air quality suggesting that the deforestation in Phase I coupled to the start of rural industrialisation and agricultural intensification using artificial fertilizers in Phase II had major detrimental environmental impacts. Terrestrial biodiversity fluctuates around the levels seen in the later part of Phase I but soil stability (Rb/Sr ratio) decreases further suggesting soil erosion had extended from the mountains above the reservoir to other parts of the county. Two phases of check dam building in the late 1980s (and later in Phase III) support the records for soil stability and sediment regulation services (sediment accumulation rates) that show a major decline through the late 1970s and 1980s as a result of continued accelerated erosion, despite reforestation schemes in 1976 and 1980. But overall, if Phase I was a period when policies destabilised soils and destroyed biodiversity, it seems that Phase II was the turning point towards destabilisation of air and water quality.

Phase III HRS with rural market liberalisation policy (1985-1998)

The period of 'HRS with rural market liberalisation' (Table 1) in Shucheng prior to 1997 is associated with a constant rural population and slowly increasing wealth, before a sharp increase in county GDP per capita in 1997-1998 as the rural population declines. Grain production also rises steadily from 1985 until a major decline in 1991, which is followed by a recovery and a return to just below former levels in 1998. Pig production rises steadily until the end of the period, aquatic and timber production both show sharp rises in the 1990s, but tea and fruit production show overall declines. These contrasting patterns of crop production are matched by large fluctuations in fertilizer usage. Interestingly, major statistical shifts in both provisioning services and the whole social-ecological State (Figure 5 and section 3) occur during the mid-1990s, suggesting a major change in Response-States connections within Phase III. Whatever the drivers of these changes, the ecological responses are equally diverse. One record for water quality (total organic carbon) shows rapid deterioration from the start of Phase III, but the other record (diatom-inferred total phosphorus) fluctuates about previous levels. One record for soil stability (Rb/Sr ratio) steadily declines through this period whereas the other record (magnetic susceptibility) fluctuates significantly in the period around 1990. There is strong evidence that some of the patterns in crop production and in the soil and water responses are climatically driven. The sharp drops in grain production and major fluctuations in soil stability at this time are consistent with the effects of the extreme rainfall and floods (1991-1992) and peak measurements of 'disaster areas' (1991-1995). Air quality continues to deteriorate in the first half of the phase before recovering and then falling back in the last years. Terrestrial biodiversity shows fluctuating values before falling rapidly from a peak in 1994 that parallels the rise in timber production. Overall, Phase III is typified by fluctuating patterns of crop production that may suggest a significant move towards trialling different crops or farming techniques but may also reflect the impact of extreme climate. Certainly, this phase sees the start of upward trends in the cash crops of timber, aquatic and fruit, and a gradual contraction of the area under cultivation. These agricultural changes continue to drive losses of regulating services.

Phase IV HRS with grain policy (1999-2003)

The end of Phase III is characterised by a fall in the rural population that stabilises in Phase IV, the period of 'HRS with grain' policy (Table 1). Cultivated land area falls, grain production fluctuates, grain productivity increases and fertilizer usage rises sharply before falling indicating that more marginal land was abandoned. Meanwhile tea plantations show a steady rise for the first time in ~15 years, and pig, fruit and aquatic production show continuations of the rising trends that started in Phase III. This shift towards lower levels of grain production as more profitable cash crops expand may explain the slow but steady growth in county GDP per capita. But some of the fluctuations in the grain data may also reflect the negative effects on agriculture by the major floods of 2002-03, which are marked by peak values for measured 'disaster area'. Data for timber production drops during this period and this may be reflected in the recovery in the records of terrestrial biodiversity. Records of soil stability show evidence for a long-term recovery (in two of the three proxy records) with an upturn in one of the records (Rb/Sr ratio). Water quality records now show rapidly declining signals possibly responding to the high levels of fertilizer usage. Out of all the regulating services, only air quality records show evidence for stabilised or constant conditions. Overall, Phase IV describes a contracting agricultural area, shifts in the choice of crop production, the highest recorded fertilizer usage and significant negative impacts on water quality.

Phase V HRS with subsidy policy (2004-2011)

The introduction of an 'HRS with subsidy' policy in Phase V (Table 1) is associated with increasing size of cultivated land area, increasing rural population, increased tea plantation area, increased fertilizer usage, rising grain yields and productivity, rising aquatic and timber production, but steadily declining pig production. The main impacts on regulating services until 2006 (when records end) are further declines in soil stability, biodiversity and water quality. Water monitoring data (lake Chaohu) between 2003-2010 show relatively high but fluctuating values for total nitrogen and chemical oxygen demand, but rising values for total phosphorus that confirm the long term downward trajectory for water quality. Overall, Phase V shows the impetus to the rural population and crop production induced by subsidies, with the associated losses of soil stability and water quality services.

Farmers' views

This section describes the results of a farmer questionnaire analysis.

Farm status

The farms in the survey are small with an average area of 0.44 ±0.68 ha (maximum 3.63 ha) supporting on average 3.7 ± 2.2 persons. Mountain farms are on average 38% smaller in area than the farms on the plain. The main crops are rice, wheat, cotton, rapeseed oil crops and maize (22%) (Figure 6a) with less rice and more maize grown in the mountains. The farmers are typically middle-aged to old, with a mean age of 52 ±15 years and modal peak 60-64 years, having worked on the same farm for 23 ±15 years (maximum 40 years). Around 70% have been educated only to primary school level. Only 19% stated that farming was their main source of income, and 93% have family members working in the town. Non-agricultural income (as % of their total income) is on average 77% ± 18%. Current government subsidies received by the farmers range from zero to 6600 Yuan/yr (~1090 USD) with an average 597 ±1106 Yuan/yr (~100 ± 180 USD) largely determined by the farm size. Subsidies to the mountain farms are on average 60% lower.

Views on farming

In general, the farmers' views on agricultural management are consistent across the groups from the mountains and plains. Not surprisingly, the overwhelming majority want to maximise profit and minimise risk. Over 90% of farmers are interested in how national agricultural policies and subsidy schemes apply to their farms, and a similar percentage keep track of market prices. A majority (71%) would like to try out new agricultural ideas, like organic or precision farming, but a larger majority (90%) think they lack the appropriate knowledge. Many farmers believe that resources for new methods are unavailable to them and are generally unprepared to invest time and money in new crops and equipment. It should be noted that there is a tendency for these attitudes to differ between the sub-groups. Farmers on the plain are the least convinced that extra resources are available but are more prepared to invest their own resources. They are also less inclined to change the land use when market prices change. Overall, a majority of all farmers (69%) do not believe that the government offers opportunities for improving farm profits. It seems that the largest influences on an individual farmer is the success of nearby farms. More than 75% of farmers would copy a neighbour's new activity if they saw that it was successful.

Views on ecological degradation

The farmers rank water quality, drought and soil quality as the most important types of ecological degradation and losses of regulating services (Figure 6b). But there are differences in the sub-groups, with mountain farmers ranking drought and rivers running dry the highest, and the farmers on the plain ranking water quality and soil quality the highest. Only 8% stated that there was no degradation. The whole group varies in identifying the main causes of degradation as chemical fertilizer and pesticide use (Figure 5c), climate change, over-cultivation, new crops/techniques and deforestation, with farmers on the plain emphasising the importance of fertilizer and pesticides compared to the mountain farmers. Off-record discussions with farmers revealed a dominant view that the responsibility for the degradation lies with the government, not with farmers themselves. In the year preceding the survey, ~60% of farmers stated that they had lost income (mean loss 11%) through an environmental factor such as crop pests, drought, typhoon winds and flooding. Overall, farmers identify the start of ecological degradation (Figure 5d) with the early 2000s (Phase IV HRS with grain), as opposed to the mid-2000s or before 2000. A higher proportion of the plain's farmers give the early 2000s as the starting date compared to mountain farmers.

Plans for the future

Around 50% of farmers state that urbanisation is a major factor limiting future agricultural development and rural incomes (Figure 5e). The next ranked factor is the cost of fertilizer and pesticides while other factors relate to global food prices, ecological degradation, the role of government and insufficient land. Higher proportions of mountain farmers identified urbanisation, the role of government and insufficient land as major limiting factors, while higher proportions of farmers on the plain identified the costs of fertilizer and pesticides and ecological degradation. Regarding future intentions, farmers are fairly evenly split (Figure 5f) between planning to rent out the land, giving the land to family or others, and having no strong plans or even abandoning the farm. Mountain farmers are less certain while farmers on the plain are more likely to consider renting out their land.

Discussion

"China's transition to sustainability should take advantage of its ability to implement massive programs that can infiltrate every aspect of society rapidly" (Liu, 2010 p. 50)

Over the 65 year-long period, farmers and the environment have responded directly and indirectly to the general trend of liberalisation, a trajectory buoyed by rising population, demands and incomes. The generally rising trends in provisioning services (Figure 5) reflect the farmers' increased profit motivation and steadily rising personal wealth that allows for improvements in the use of hybrid crops, mechanisation, fertilizer and pesticides: a process of 'land use intensification'. In contrast, there are parallel long-term losses or degradation of some regulating services, notably soil stability, air quality and water quality (Figure 4). These divergent trends constitute a long-term trade-off for food and income against environmental quality; a socially and politically acceptable trade-off that has strengthened each decade since the 1980s.

In terms of FESP, the strongest links within the social-ecological system (Figure 2) have been processes operating in the States component, specifically the Adaptation by farmers to successive national policy Response decisions aimed at liberalisation, increasing the Service Provision of agricultural goods through intensification. This has driven investment in technologies and fertilizers, and subsequent incomes, which has created a positive feedback loop. As the positive loop has strengthened, the Impacts on Service Provision have been positive for provisioning services and largely negative for regulating services. However, there remains a disconnect by government of the link between Impacts on all Services Provision and States through Response policies that Adapt to Trade-offs and Valuation of Services. Even though there is clear evidence for Trade-offs between provisioning and regulating service provision, the Responses in terms of national policy have largely been through Mitigation effects on economic Drivers and land use Pressures than through Adaption in terms of direct environmental protection. For example, the Phase IV 'HRS with grain' marketization policy period saw a shift away from grain cropping with a sharp drop in total grain yield as farmers chose cash crops over grains. This is reflected in a slowing down in water quality degradation and possibly some recovery in biodiversity and soil erosion (Figure 4) temporarily suspending the trade-off, but only as an indirect result of policy Responses affecting economic Drivers. The change in policy Response during the following Phase V 'HRS with subsidy' period (Figure 3), when grain crops were 'made' more profitable to counter declining crop yields, shows the direct link between Impacts on Service Provision, Valuation of Services and Responses. Within two years, fertilizer usage and grain yields renewed their long-term rise and, as a result, water quality degradation accelerated and there is some evidence for declining levels of soil stability and terrestrial biodiversity (Figure 4). As the subsidy system became established, the levels of county GDP per capita grew at an unprecedented rate. The evidence suggests that during these phases the government and farmers responded rapidly to each other's decision-making rather than the State of the environment.

In terms of the effects of Drivers and Pressures on the States, the strongest direct evidence is in terms of the short-term, rather than long-term impacts of weather events on crop yields. But overall, the strongest effects of Responses on exogenous Drivers and Pressures has been through national economic growth, and especially urbanisation within rural areas, that will have strengthened the Shucheng farming system through increasing market demand for crops and providing additional sources of family income. Farmers have acted primarily as Ecosystem Service Providers and do not appear to have influenced, or been strongly influenced by, national policy Responses that directly address Impacts on regulating services. This despite the widely held views of farmers that environmental protection and restoration are the government's responsibility.

The question now is whether the nature of the trade-off is changing to one where continued and successful exploitation of provisioning services is directly undermined by a decline in regulating (and supporting) services. The long-term declines in soil stability and, especially, in water quality reflect the gradual losses in ecological resilience, with the sharp downward declines in water quality in the 1970s and at the end of the 'HRS with grain policy' period indicative of critical transitions from one steady state to another (Zhang et al., 2015). These declines could be caused by long-term positive feedback loops, such as adding artificial fertilizers to gain year-on-year productivity gains while natural soil fertility (encompassing organic matter, soil structure and soil depth) continually deteriorates from over-cultivation. However, there is no direct evidence that the trade-offs over several decades significantly constrained provisioning services (although the shift in downstream lake water quality will likely impact lake fisheries). For example, the fluctuating and low grain yields between 1989-2004 seem to be less the result of biophysical constraints and more the combined effects of inefficient grain production before subsidies were introduced, and extreme climate impacts. Only the last two years of grain yields (2010 and 2011) that show the first downturn since 2001 could indicate a long-term cumulative and negative impact on crop productivity: the corollary to the environmentalist's paradox (Raudsepp-Hearne et al., 2010).

Even if ecological degradation is currently insufficient to reduce crop productivity, there is strong evidence that the state of soil, fluvial and lake systems in Shucheng may be shifting (or in the case of lakes have already shifted) to undesirable states (Zhang et al., 2015). The majority of farmers questioned were aware of the changes in provisioning and regulating services shown in this study, at least since Phase III. They identified water quality as the most degraded regulating service, especially those living on the plain, and to some extent soil quality, with fertilizers and pesticides as the main causes of degradation. Interestingly, changes in the local climate were also identified, especially from the mountain farmers whose livelihoods are sensitive to drought and rivers drying up, which is consistent with the PCA evidence for associations with precipitation in the 1980s (Figure 5) and records of extreme climate events impacting on crop production and soil stability, especially since the 1990s when mean temperatures began to rise (Figure 3). Less consistent with the biophysical records are the farmers' perceptions of when the ecological degradation began, which they generally identify as the period since the mid-2000s. This period includes a sharp decline in water quality but significantly underestimates the long-term declines in water quality, air quality and soil stability that started around the time the HRS was introduced in the 1980s (Figure 4).

What are the implications for designing and implementing new policies over the next five to thirty years? In order to address the losses of regulating services, farming has to become more efficient with respect to the use of soil, water, pesticides and fertilizers. Successful Land Circulation could bring more mechanisation of manual processes, leading to more efficient delivery of seed, fertilizer and pesticide, and importantly produce rental incomes for absent farmers. However, as observed elsewhere in China (Du & Bo, 2011; Chen & Du, 2014), Shucheng farmers are uncertain about what should happen to their farms with 35% having no strong plans. Even on the plains only 45% of farmers are considering the Land Circulation option and, in the mountains, where field sizes are mainly constrained by topography, farmers are even less keen. It follows that urgent delivery of scientific and place-based practical advice and guidance directly to farmers is crucial to the success of any current or future land management policy (Cui et al., 2018). This all points strongly to a need for a significantly improved system of information and technology transfer, probably involving a more efficient coordination between agencies. Agriculture Technology Extension Centres exist but many of the personnel are not qualified to give up-to-date advice (Zhang Weijian personal communication) and increasingly focus on farm organisation issues and sales. In selected counties, the Science and Technology Backyard programme (Zhang et al., 2016) that promotes agricultural scientists living in villages among farmers shows encouraging results with respect fertilizer management, irrigation and crop yields. But generally, there is a major gap between making policy Responses at the national level and implementing the appropriate practices for Adaptation at the local level.

The Opening-Up Reforms in the late 1970s set Chinese agriculture on a path that has tracked the national rising level of wealth: a path-dependent union between agricultural intensification, poverty alleviation and ecological degradation. Where Shucheng differs from the average county is in the overall lower income levels that are partly due to the marginal nature of farmland in the mountains. Nevertheless, our study is perhaps representative of the hundreds of agricultural communities in marginal landscapes across China, supporting millions of people, but which lag behind the general economic growth. These communities may not engage in the most intensive agriculture but a long history of poor practices may still jeopardise the long-term sustainability of ecosystem services in these areas. The urban lure of higher incomes is possibly stronger than in wealthier communities making the viability of land tenure reforms, the transfer of information and technology, and succession of the family farm far less certain as young people reject farming as a livelihood. As the current farmers retire over the next 10-15 years, the issue of low farm incomes is likely to become pivotal in any debate about sustainable agriculture in China.

Conclusions

- Shucheng represents a policy-responsive farming community that has driven up levels of crop productivity. This has led to long-term ecological degradation, a situation viewed (in

2012) as an acceptable trade-off. Individual bottom-up actions framed by top-down national policy and embedded in contemporary agricultural culture have led to continuing losses of regulating services that reduce the resilience of the agricultural system and threaten to undermine crop yields in the future. Neither the farmers nor the state has directly determined the trade-off. It is more an emergent feature of farmers adapting to a long-term policy of liberalisation playing out over multi-decadal timescales.

- In general, farmers have been highly responsive to policies that drive positive feedback loops by developing and exploiting provisioning services according to levels of profits and subsidies that, in turn, raise incomes. The periods of 'HRS with grain' and 'HRS with subsidy' demonstrate the negative and positive effects of policy on farmers, as shown by fluctuating crop yields. The relationship between poverty alleviation and ecosystem services has been coupled strongly through provisioning services and less through regulating services. Indeed, the liberalisation process that has led farmers to improve agricultural productivity and their own wellbeing has not led to a stronger sense of stewardship over the environment.

- Farmers identify correctly the main types of long-term ecological degradation and the proximate causes. But they perceive the start of the degradation significantly later than the scientific evidence. The results show that the extent of degradation is only realised after rapid declines: otherwise masked by the process of 'creeping normalcy'. Water quality has deteriorated most rapidly and there is evidence that critical thresholds may have been passed in downstream lake ecosystems. Extreme climate events can deliver direct impacts on both provisioning and regulating services and there is evidence that the long-term warming trend may also have an impact on services. The long-term rates of decline in regulating services are unsustainable but in the absence of relevant policy farmers show little motivation to make restorative actions.

- Unfortunately, urbanisation, low farm incomes, low educational attainment levels and an aging demographic still represent barriers to viable farming. Incomes from farm produce and government subsidies are still low, and insufficient to maintain a farming family whose head is normally middle-aged or close to retirement. Together with the lack of information transfer and technology, today's farmers are not in a strong position to make changes that would simultaneously produce step-changes in income and reverse the negative ecological trends. Land Circulation, designed to overcome inefficient farm sizes, may not be taken up widely.

- The similarities between the long-term trends observed at Shucheng and other rural counties in eastern China (e.g. Zhang et al., 2015) indicate that the findings may apply more broadly. This indicates that maintaining or increasing current productivity levels while simultaneously slowing or reversing the losses of regulating services nationally requires new national or regional policies that promote bottom-up, restorative influences on the environment and a sense of stewardship within an inter-generational strategy for farm land use and management. Future national policies need to embrace systems perspectives and focus on delivering scientific and place-based information and technology to farmers through environmental advisors.

Declaration of interest statement

None of the authors has any relevant interests to disclose.

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Appendix

Questionnaire survey

Farmer Characteristics:

1. How long have you lived on and farmed this land? ______________________________________
2. How old are you? __________
3. What is your education level? ____
4. How many people are supported by (or are dependent on) this farm? ________________________
5. What relation are these people to you? (e.g. spouse, children (adult or child), other family, workers, other) ____
6. Do you own, rent or manage this land? (please specify) __________________________________
7. How much land does this farm cover? ____
8. What is the land currently used for? Please give land-use type and approximate area (e.g. crops (please specify), grass/hay, trees, for livestock, fallow, industry, other)?

Land use type	Area
____	_________________
____	_________________
____	_________________
____	_________________

9. What farm equipment do you have access to? (include those you can rent) ____________________
____
10. Do you sell crops/livestock/timber and their products for profit? ____________________________
    a. If so, who do you sell to (e.g. neighbours, local market, co-op, commercial buying agent, food processing, etc.)? ____
11. Do you and your household have any non-agricultural income generating activities? If so:
    a. What are these? ____
    b. About how many hours a week do you (or other members of your household) spend on these activities? ____
    c. Does this income contribute significantly to that from the farm? ______________________

Land-Use Change:

12. Have you changed the land use of any part of your farm, or bought/sold land, in the last 10 years? __
13. If so, what did the land use change from and to? ____
____
____
____
_
14. Why did you make this change? (please tick all that apply)
    - ☐ To make more money
    - ☐ Previous land-use became uneconomic
    - ☐ Changes in yield or productivity of land
    - ☐ Changes in water availability/ climate/weather
    - ☐ Took an opportunity to try new crop/technology/enterprise
    - ☐ My neighbours tried this
    - ☐ Suggested by family or friends
    - ☐ To minimise risk
    - ☐ Lack of labour, time or other resources please state______________________
    - ☐ Changes in subsidies or market prices
    - ☐ Incentives or initiatives from local/national government or EU
    - ☐ To maintain or improve the quality of the land
    - ☐ Other, please specify ______________ ______________________________
15. What will happen to this farm when you retire? ____

Environmental issues:

16. Which part of environment do you think is degrading most seriously? (   )
A. Forests B. Air pollution C. Water quality D. Flooding E. Drought F. Soil erosion
G. Soil quality H. Biodiversity loss I. Others (please specify)

18. What do you think has caused the degradation? (   )
A. Fertilizer usage B. Climate change C. Deforestation D. Land use change
E. Industrialization F. Others (please specify)

19. When do you think the degradation started? (   )
A. 5 years ago B. 10 years ago C. 20 years ago D. 30 years ago

20. Did natural disasters or other environmental problems cause you to lose money last year? If yes,

What are the reasons ( ), and how much do you lost ( ), and what is the percentage it accounting for your total annual income? ( )

21. Which part of natural environment is more important to you, please rank them from 1 to 5, 1 represent less important and 5 represent most important.
Soil erosion ( ) Water pollution ( ) Biodiversity loss ( ) Air pollution ( )

22. Where do your agricultural skills come from? ( )
A. Previous generation B. Labouring experience C. Advisor D. Others (please specify)

23. Do you have idle land? If yes, why? ( )
A. Land quality degradation B. Lack of labour C. Agricultural price is too low
D. too far from home E. Others (please specify)

24. What kind of subsidies did you receive last year, and how much were they worth?

25. What factor do you think limits the agricultural development and rural income in this area? ( )
A. Environment degradation B. Urbanization C. Policy D. Global food price E. Others (please specify)

26. To what extent do you agree or disagree with the following statements:	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
I change the land use frequently				
I want to maximise my profit				
I want to minimise risk				
I would like this farm to stay in the family				
I want to maintain traditional farming methods				
I am concerned that new people moving into the area will ruin its character				
I watch what my neighbours are doing with their land				
If I see my neighbours are doing well with a new farm method or activity, I would try it too				
I would like to try out new agricultural methods and activities				
I am not interested in new ideas and schemes, e.g. organic farming, agricultural environmental management, precision farming				
I feel that I lack the knowledge to try new farming methods and activities				
I would like to research new farming methods and activities				
I believe that I can get the resources to try new farming methods and activities				
I am prepared to invest time and money in new farm equipment, methods or crops				
I am interested in national agricultural policies and subsidies and how they apply to my farm				
I keep track of market prices				
I will change my land use if market prices change significantly				
I try to anticipate changes in the market				
I am not interested in agricultural policies and subsidies and how they apply to my farm				
I think that government offers opportunities for improving farm profits in this area				
I will change land use if physical farming conditions change				

Please use this space for any information you didn't have space for earlier.

Figures

Figure captions

Figure 1. Shucheng County, lake Chaohu and the surveyed towns in the Chaohu catchment (inset shows location in eastern China).

Figure 2. A Framework for Ecosystem Service Provision based on a modified Driver-Pressure-State- Impact-Response framework (Rounsevell et al., 2009).

Figure 3. Drivers, Pressures and Impacts on Shucheng county 1950-2010: a) Total population, GDP/capita and population working in agriculture (%); b) annual mean temperature (°C), annual precipitation (mm) and climate-related disasters measured as 'disaster area' (km^2); c) cultivated land area (km^2), tea garden area (km^2), and Anhui fertilizer usage (10^5 t).

Figure 4. States of ecosystem services in Shucheng county 1950-2010: a) normalised provisioning services – total grain yield, pigs, fruit, tea, aquatic products, and timber; b) normalised soil stability and sediment regulation regulating services – sediment magnetic susceptibility, sediment accumulation rates and Rb/Sr geochemical ratio; c) normalised air quality regulating services – sediment Pb and soot concentrations; d) normalised water quality regulating services – diatom-inferred total phosphorus (DI-TP) and sediment total organic carbon (TOC) - with monitoring records (mg L^{-1}) of total phosphorus (TP), total nitrogen (TN) and chemical oxygen demand (COD); e) normalised biodiversity – rarefaction index of terrestrial pollen taxa. Vertical dashed lines delineate agricultural policy Phases I-V where HRS abbreviates Household Responsibility System (Table 1) and grey vertical bars show Great Leap Forward and Cultural Revolution.

Figure 5. Biplot of the Principal Component Analysis of the Shucheng data from 1959-2006 showing the first (PC1; ~58% of the variance) and second (PC2; ~12% of the variance) principal components for each year and the variables within the correlation circle. Three clusters can be clearly delineated, representing a) the Great Leap Forward and the early 1960s

(red), b) the Cultural Revolution and the early Household Responsibility System (green), and c) the Household Responsibility System and market liberalisation (blue). The variables are labelled as: Pop.Tot. (Total Population), Pop.Rur. (Rural Population), Tmp. (Temperature), Prcp. (Precipitation), Tmp.Hei. (Temperature in Heifi), Prcp.Hei. (Precipitation in Heifi), TeaGard (Tea Garden Area), Fert.Anh. (Fertiliser Usage in Anhui), Cultv. (Cultivated Area), Yield.t (Total Grain Yield), Yield.kgha (Grain Yield per hectare), Pigs, Fruit, Tea, Aquatic (Aquatic Products), Timber, Biodiv (Biodiversity), SoilStab.Xfd (Soil Stability by Xfd), SoilStab.RbSr (Soil Stability by Rb/Sr), Sed Reg (Sediment Regulation by MAR), Air (Air Quality by Lead), Soot (Air Quality by Soot), DITP (Water Quality from DI-TP), TOC, Sed (Sediment Quality).

Figure 6. Farmers' questionnaire responses: a) crops grown; b) main types of ecological degradation; c) causes of ecological degradation; d) start date of ecological degradation; e) barriers or threats to farming; f) personal plans for the future. Data plotted with highest 'total' responses to the left, where 'total' data refers to responses by all farmers (n=68), and 'plains' and 'mountains' refer to subsets of respondents farming the lowlands (n=35) and (n=33) hilly lands respectively. Percentage data in a), b), c) and f) do not add to 100% because farmers were free to choose more than one answer.

Figure

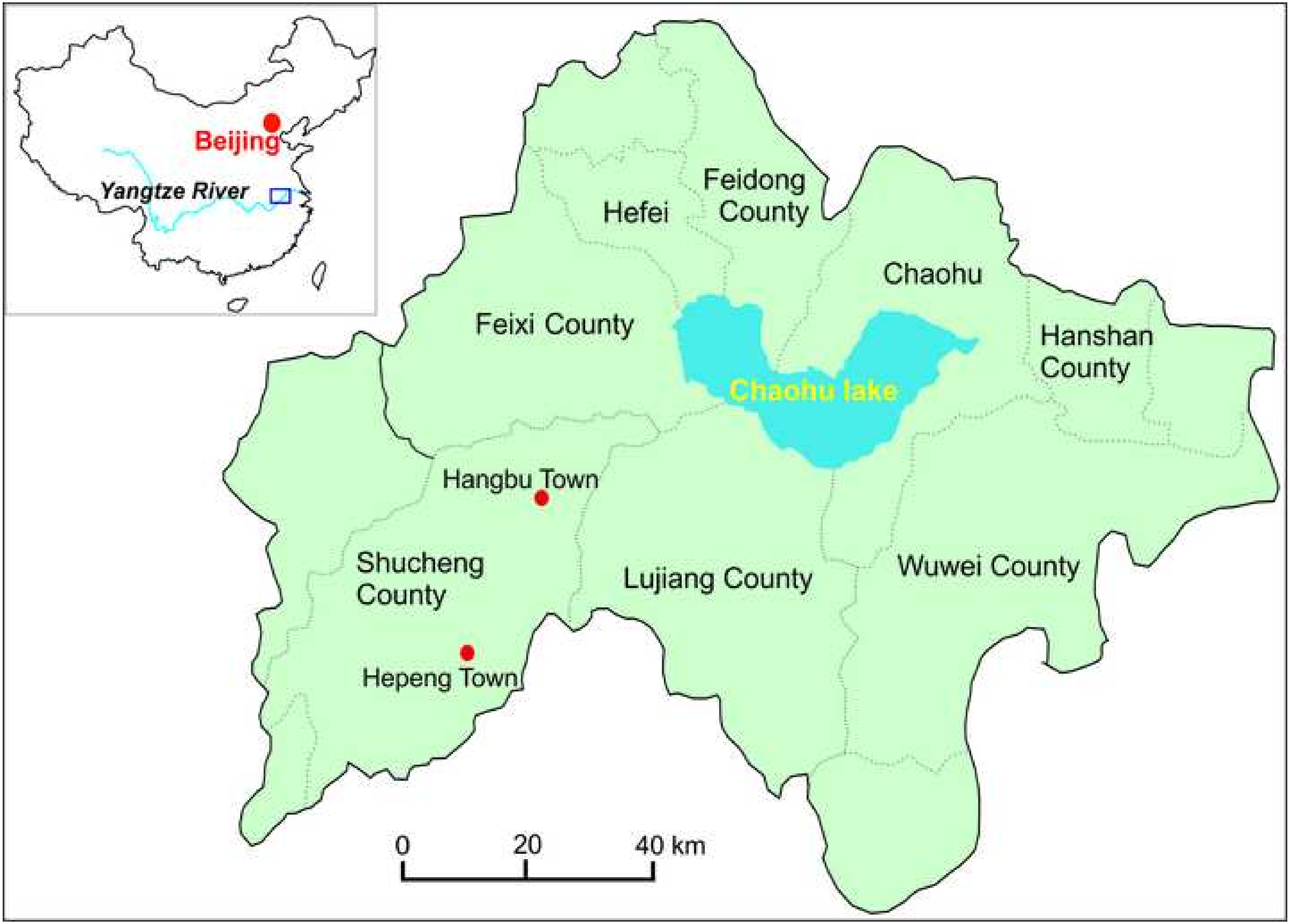
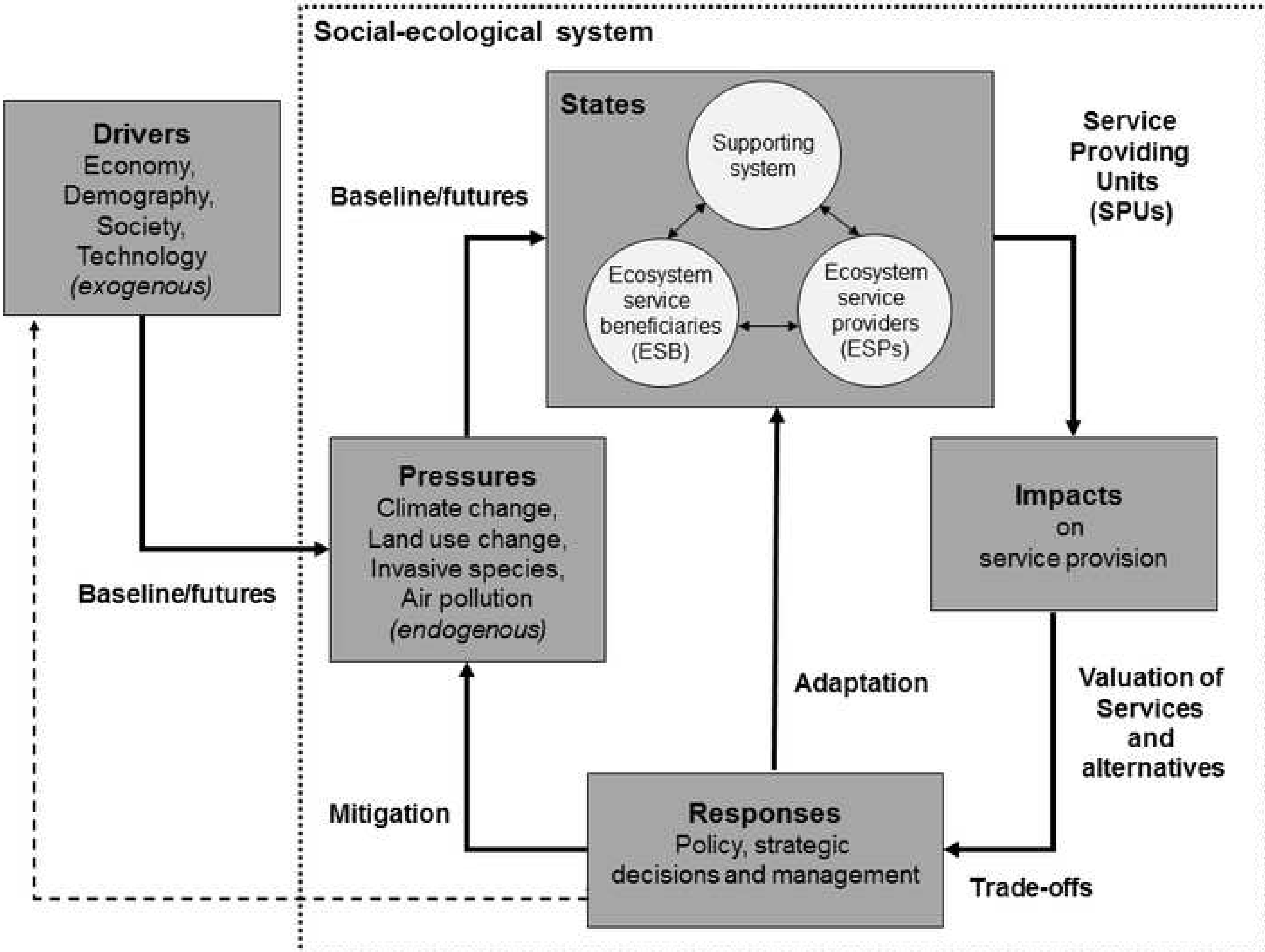
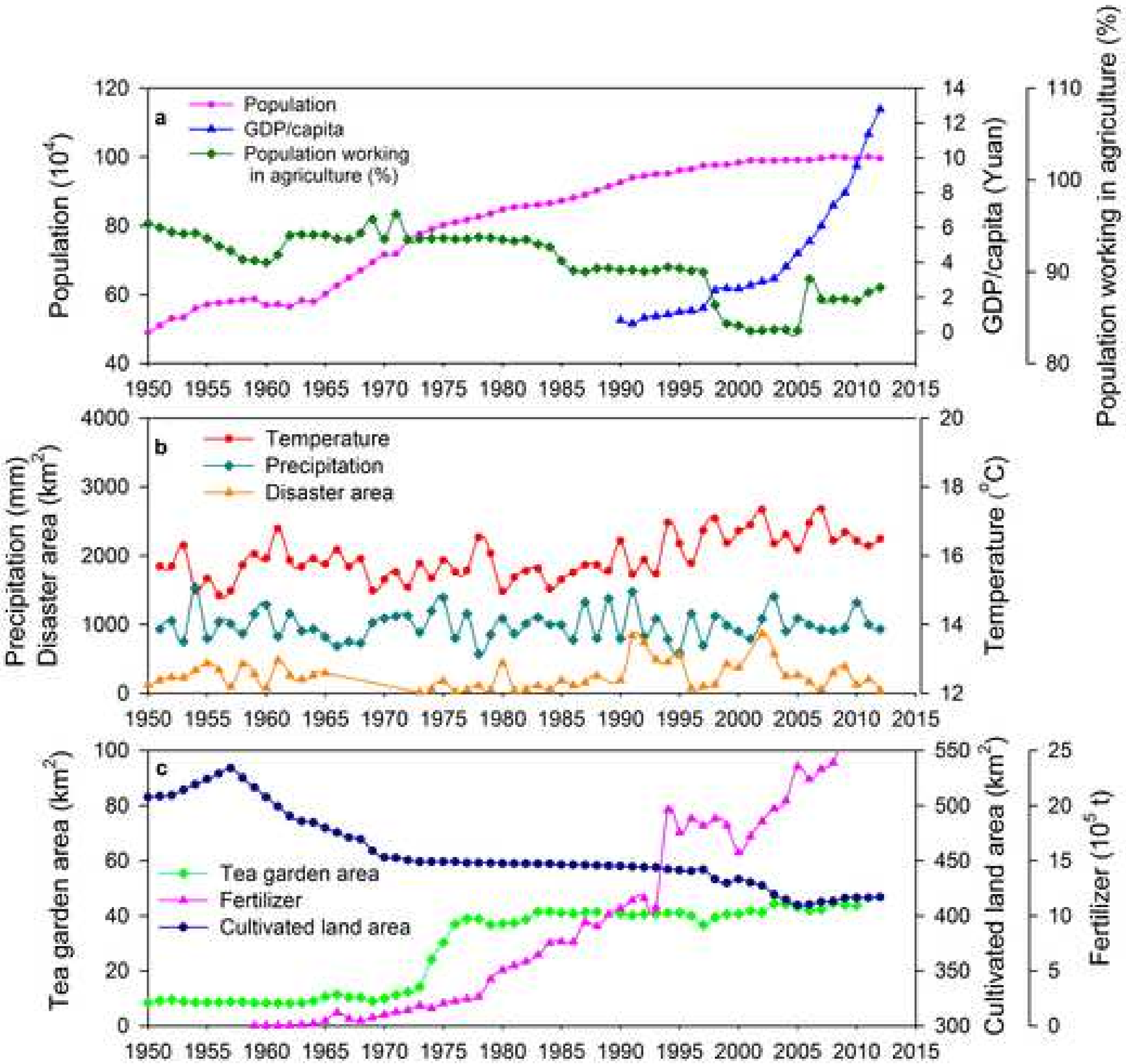

Beijing
Yangtze River
Hefei
Feidong County
Chaohu
Feixi County
Hanshan County
Chaohu lake
Hangbu Town
Shucheng County
Lujiang County
Wuwei County
Hepeng Town
0
20
40 km

Figure 2



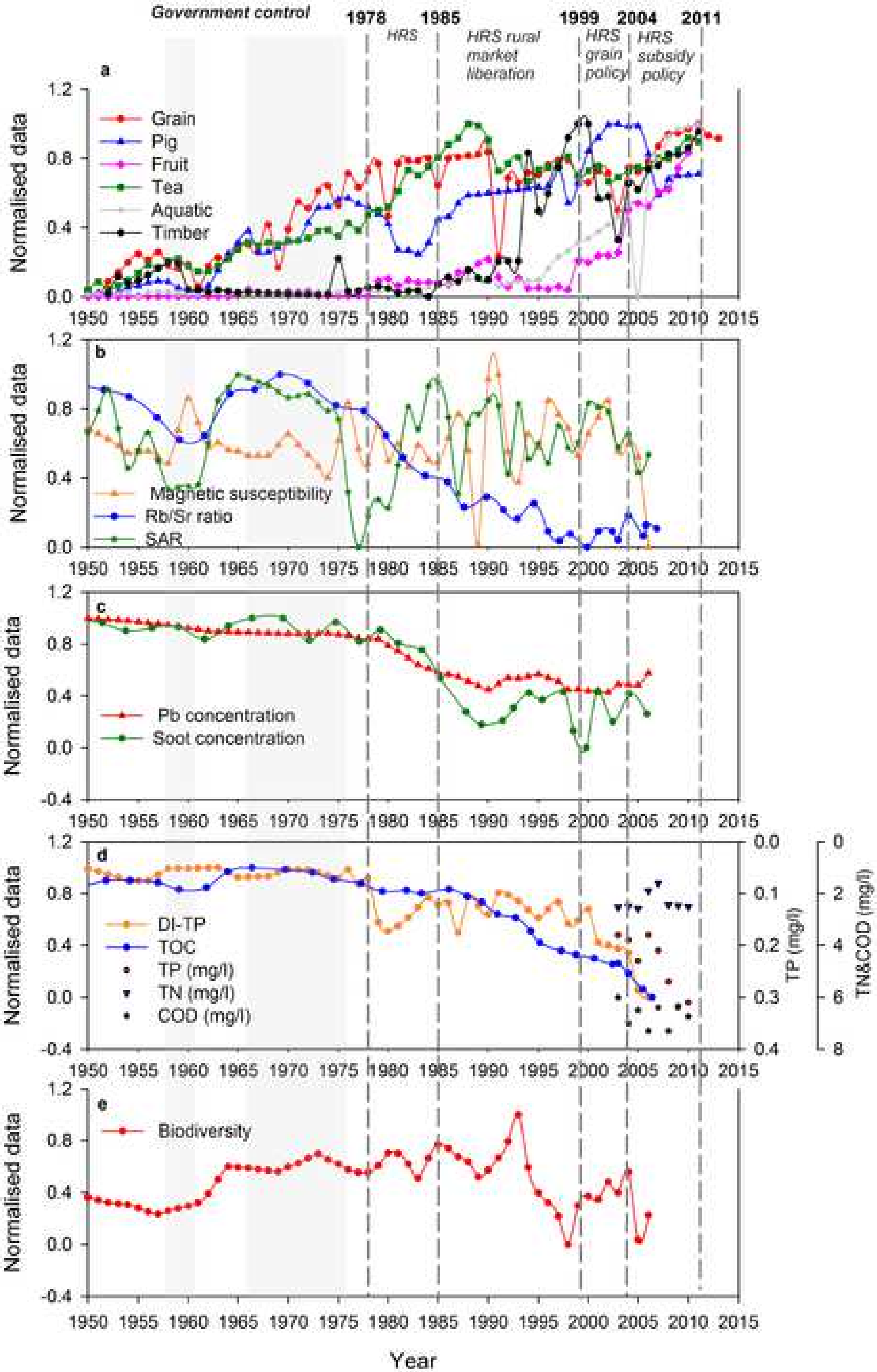
Social-ecological system
Drivers
Economy,
Demography,
Society,
Technology
(exogenous)
Baseline/futures
States
Supporting system
Ecosystem service beneficiaries (ESB)
Ecosystem service providers (ESPs)
Service Providing Units (SPUs)
Baseline/futures
Pressures
Climate change,
Land use change,
Invasive species,
Air pollution
(endogenous)
Impacts
on
service provision
Adaptation
Valuation of Services and alternatives
Mitigation
Responses
Policy, strategic decisions and management
Trade-offs

Figure 3



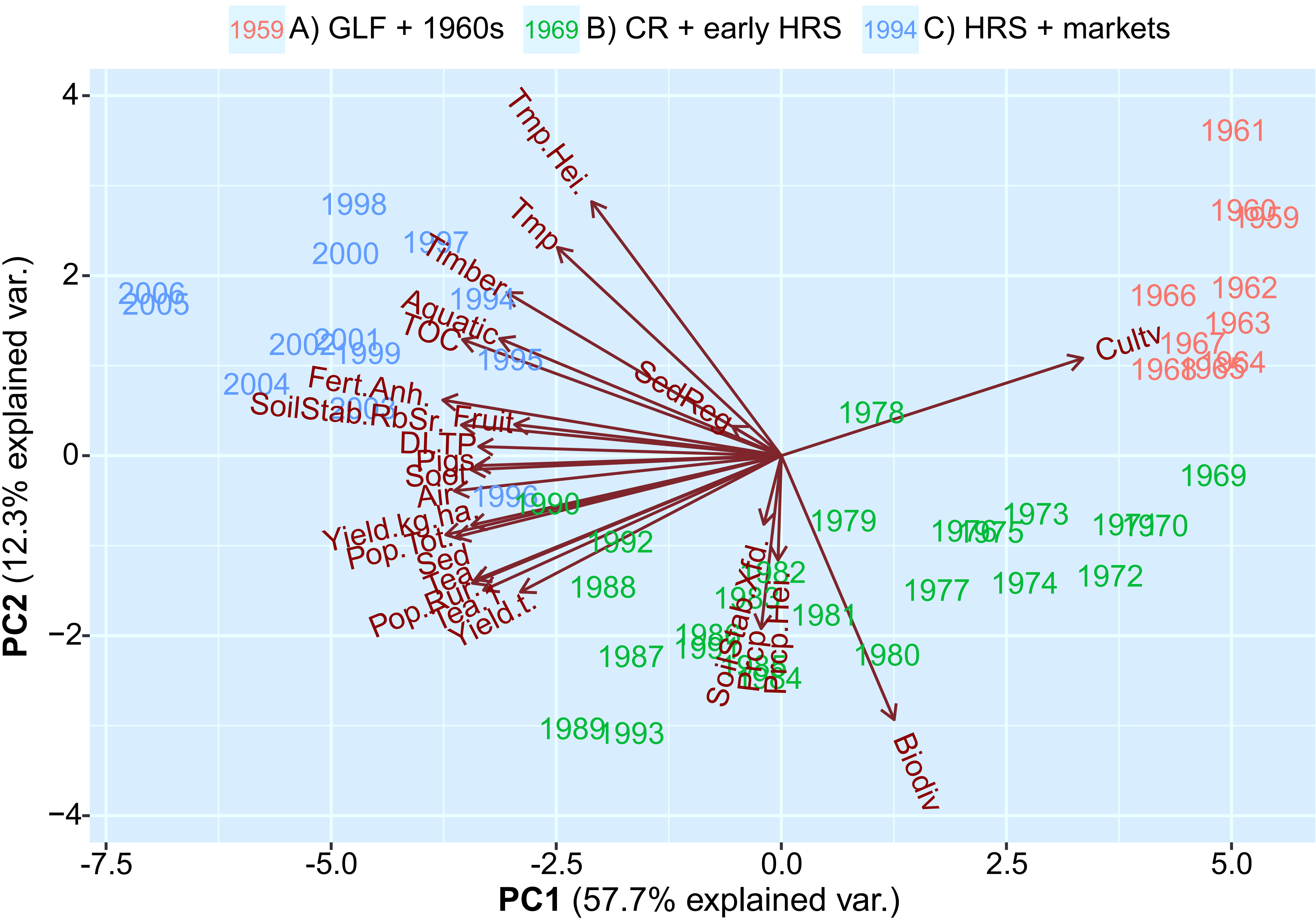
a
Population
GDP/capita
Population working in agriculture (%)
Population (10^4)
GDP/capita (Yuan)
Population working in agriculture (%)
b
Temperature
Precipitation
Disaster area
Precipitation (mm)
Disaster area (km^2)
Temperature (°C)
c
Tea garden area
Fertilizer
Cultivated land area
Tea garden area (km^2)
Cultivated land area (km^2)
Fertilizer (10^5 t)

Figure 4



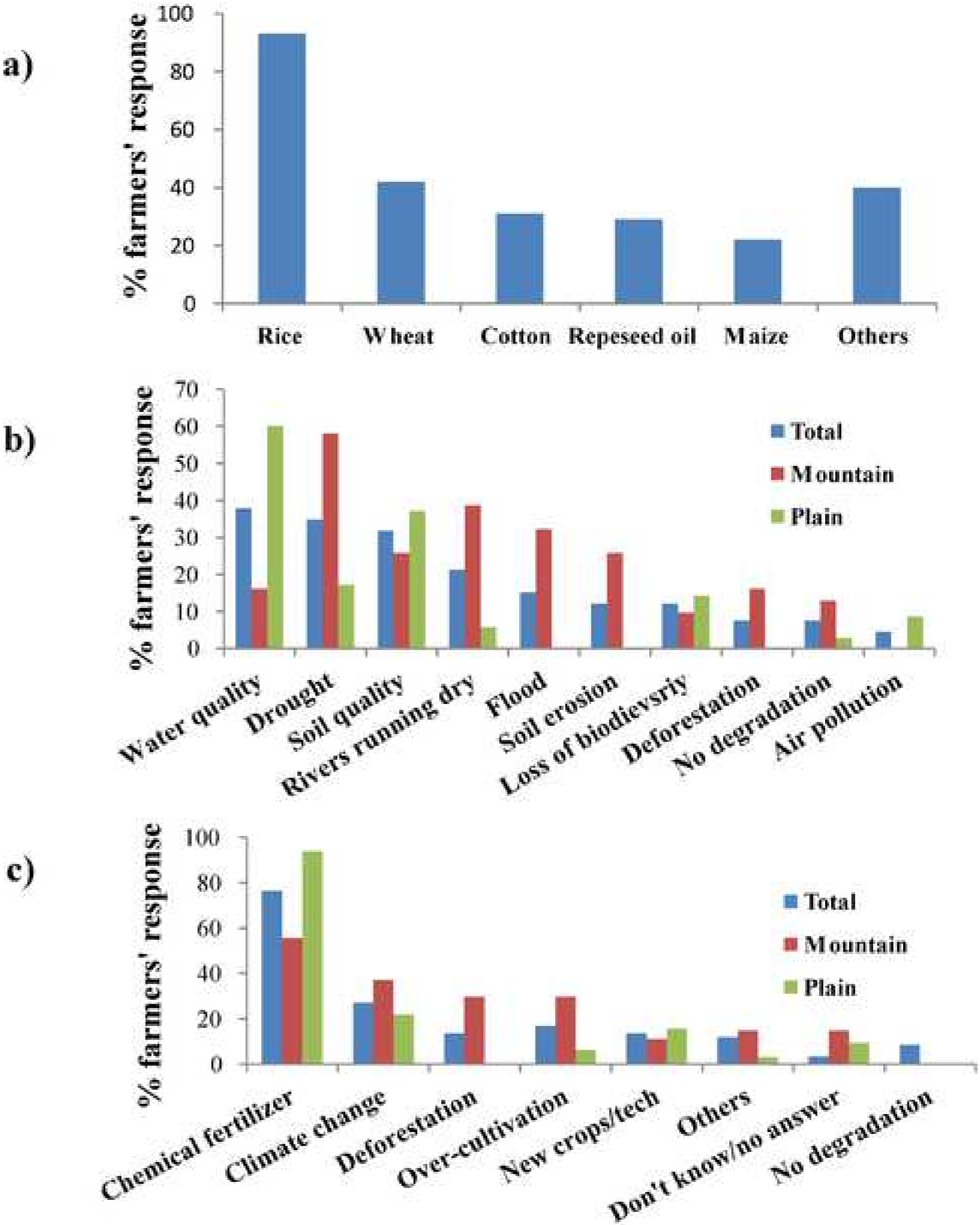
Government control
1978
1985
1999
2004
2011
HRS
HRS rural market liberation
HRS grain policy
HRS subsidy policy
a
Grain
Pig
Fruit
Tea
Aquatic
Timber
b
Magnetic susceptibility
Rb/Sr ratio
SAR
c
Pb concentration
Soot concentration
d
DI-TP
TOC
TP (mg/l)
TN (mg/l)
COD (mg/l)
TN&COD (mg/l)
e
Biodiversity
Normalised data
Year

Figure 5

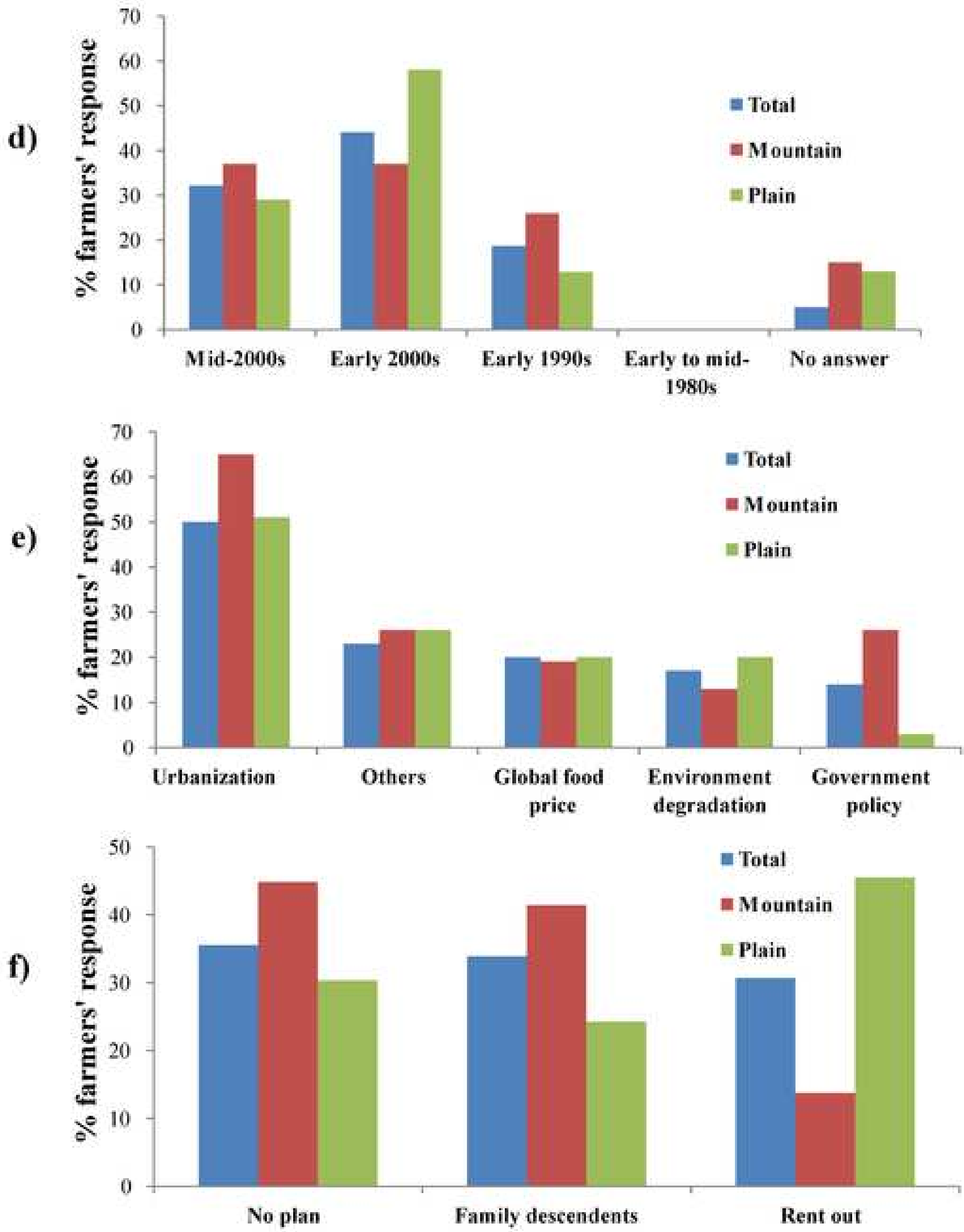


1959 A) GLF + 1960s
1969 B) CR + early HRS
1994 C) HRS + markets
PC1 (57.7% explained var.)
PC2 (12.3% explained var.)
Tmp.Hei.
Tmp
Timber
Aquatic
TOC
SedReg
Cultv
Fert.Anh.
SoilStab.RbSr.
Fruit
DLTP
Pigs
Soot
Air
Yield.kg.ha.
Pop.Tot.
Sed
Tea
Pop.Rur.
Tea.t
Yield.t.
SoilStab.Xfd.
Prcp
Prcp.Hei.
Biodiv

Figure 6a


a)
% farmers' response
100
80
60
40
20
0
Rice
W heat
Cotton
Repeseed oil
M aize
Others
b)
% farmers' response
70
60
50
40
30
20
10
0
Total
Mountain
Plain
Water quality
Drought
Soil quality
Rivers running dry
Flood
Soil erosion
Loss of biodievsriy
Deforestation
No degradation
Air pollution
c)
% farmers' response
100
80
60
40
20
0
Total
Mountain
Plain
Chemical fertilizer
Climate change
Deforestation
Over-cultivation
New crops/tech
Others
Don't know/no answer
No degradation

Figure


d)
% farmers' response
0
10
20
30
40
50
60
70
Mid-2000s
Early 2000s
Early 1990s
Early to mid-1980s
No answer
Total
Mountain
Plain
e)
% farmers' response
0
10
20
30
40
50
60
70
Urbanization
Others
Global food price
Environment degradation
Government policy
Total
Mountain
Plain
f)
% farmers' response
0
10
20
30
40
50
No plan
Family descendents
Rent out
Total
Mountain
Plain