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## Reply on RC3

Bojie Fu et al.

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Author comment on "Coupling human and natural systems for sustainability: experience from China's Loess Plateau" by Bojie Fu et al., Earth Syst. Dynam. Discuss.,  
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Thank you for your valuable suggestions and the time that you have spent reviewing our manuscript. We will revise our manuscript according to your suggestions. Below are the reviewer's previous comments, followed by our responses.

Sincerely,

Bojie Fu (on behalf of the author team)

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Reviewer #3 (General comments):

The manuscript entitled "Coupling Human and Natural Systems for Sustainability: Experiences from China's Loess Plateau" proposed a conceptual cascade framework of "Pattern-Process-Service Sustainability" to observe, analyze and predict the dynamics of coupling human and natural system (CHANSs). The manuscript introduced the components of the framework in length and illustrated a review of CHANS research in terms of coupling landscape patterns and ecological processes, linking ecological processes to services, and promoting social-ecological sustainability.

It is well known that Loess Plateau (LP) in China suffered severe soil erosion historically and achieved successful vegetation restoration in recent decades, and extensive studies have been conducted on the CHANS of the LP, so it is an ideal region for summarizing research experiences of CHANS.

Overall, this is a well written manuscript without any apparent flaws. The article tackles a relevant topic, certainly of interest to the readership of the journal. However, some details and aspects are not clearly expressed. A list of the main issues is provided below in a constructive spirit. I also include a (non-exhaustive) list of style suggestions and grammar issues. I recommend minor revision.

**[Response]** We thank you for your positive comment.

Some revisions to manuscript are needed:

Abstract:

**[Reviewer #3 Comment 1]** This manuscript focused on the conceptual cascade framework of "Pattern-Process-Service-Sustainability" to understand the dynamics of CHANS, but the meaning of this framework is missing.

**[Response]** Thank you for your comment. We will add the meaning of this framework in the Abstract: "To help understand the dynamics of a coupled human and natural system (CHANS) and support the design of policies and measures that promote sustainability, we propose a conceptual cascade framework of "Pattern-Process-Service-Sustainability", which is characterized by coupling landscape patterns and ecological processes, linking ecological processes to ecosystem services, and promoting social-ecological sustainability."

**[Reviewer #3 Comment 2]** I thought the novelty of this manuscript is the proposed framework, but in LL.70-71, it described that "Over the last 20 years, researchers have conducted extensive studies on the CHANS of the LP using the 'Pattern-Process-Service-Sustainability' framework", then what is the originality of this manuscript? It should be clearly stated.

**[Response]** Thank you for your comment. Indeed, the novelty of this study is the proposed framework, which can help researchers better observe, analyze, and understand the dynamics of CHANS and support the design of policies and measures that promote sustainability. Previous studies in the LP were not guided by this framework and most of them separately focused on the landscape patterns, ecological processes, or ecosystem services. Our paper proposes this framework by summarizing research experiences from these studies in the LP. We will revise the sentence to emphasize the novelty of this study: "Over the last 20 years, researchers have conducted extensive studies on the landscape patterns, ecological processes, and ESs of the LP, making it an ideal region for summarizing research experiences and providing guidance for the CHANS studies."

Introduction:

**[Reviewer #3 Comment 3]** The argument of proposed framework is well established, but the knowledge gap of current understanding towards CHANS is missing.

**[Response]** Following your suggestion, we will summarize the knowledge gap of current understanding as: "As CHANSs involve multiple natural and human processes interacting at different scales, this complexity poses a challenge for researchers to understand their dynamics (Liu et al., 2007; Nelson et al., 2007; Rocha et al., 2015; Gunderson et al., 2017). However, research paradigms that explicitly guide sustainability practices based on deepened understandings of the interactions between humans and nature are still limited."

**[Reviewer #3 Comment 4]** The explicit aim of this research is also missing.

**[Response]** According to your suggestion, we will add the aim of this research as: "To fill this knowledge gap, we propose a conceptual cascade framework of "Pattern-Process-Service-Sustainability" (Fu and Wei, 2018) to better observe, analyse, and understand the dynamics of CHANSs and promote their sustainability."

China's Loess Plateau:

**[Reviewer #3 Comment 5]** The success of the GTGP is shown in Figure 2 with NDVI index, but in the context, there is no description of NDVI, neither an explanation of the Figure 2 indicates.

**[Response]** Following your suggestion, we will add several sentences in Section 3: "Since

the beginning of the 21<sup>st</sup> century, the vegetation coverage in the LP has significantly increased and soil erosion has been effectively controlled (Fu et al., 2011b). According to the MODIS NDVI data, more than 70% of the LP showed a significant “greening” trend from 2000 to 2015, mainly distributed in the central and southern parts (Figure 2).”

Application of the framework in the LP:

**[Reviewer #3 Comment 6]** The farmland in land-use changes is a type of also human activities, why it is divided into natural system?

**[Response]** Thank you for your comment. The phrase “land-use changes” more highlights the land types conversion caused by human activities. We will change it to “land use and land cover” (LULC), which is more related to the spatial pattern or configuration of natural systems. Besides, the phrase LULC is more neutral, and human land use such as cultivated land is a part of LULC.

**[Reviewer #3 Comment 7]** The human system and the linkage between natural system and ESs did not well depict in the context.

**[Response]** Following your suggestion, we will revise the first paragraph in the Section 4.2 to illustrate the linkages between natural processes and ESs, and the impact of changes in ES on local residents: “By coupling patterns and processes, researchers found that the ecological restoration program has altered the soil erosion and water-carbon processes and flow-sediment relationships in the LP (Feng et al., 2016; Wang et al., 2016). As ecological processes underpin the delivery of ESs, changes in these natural processes in the LP will affect ESs that local residents depend on (Fu et al., 2013). Linking ecological processes to ESs can help understand the complex relationships among ESs and support optimized ecosystem management measures (e.g., minimize trade-offs and maximize synergies) and sustainability of CHANSs (Fu et al., 2013). Regarding this aspect, a large number of studies about land use and land cover change, ES assessments, and their trade-off and synergy analysis have been conducted in the LP over the past two decades.”

**[Reviewer #3 Comment 8]** The introduction of social-ecological sustainability mainly focusses on the enhancement of targeted policies and management instead of the explanation and the coupling relationship of each component, it should be well-structured like 4.1 and 4.2.

**[Response]** Thank you for your comment. According to the framework, Section 4.3 is to diagnose the causes of the unsustainable status of CHANSs, and support the design of policies and measures that promote sustainability. We will further elaborate the meanings and aims of our framework, and explain the coupled relationships between system components before giving targeted suggestions.

We will add these sentences in Section 2: “The practical implications of CHANSs studies are to promote the “Sustainability” of the coupled systems (Ostrom, 2009; Liu et al., 2013a). A deep understanding of “Pattern-Process-Service” interactions can help us figure out the causes of the unsustainable status of a CHANS and provide the scientific basis for designing policies or measures that promote its sustainability. Both environmental changes and human activities can affect the interactions between landscape patterns and ecological processes, and directly or indirectly affect the ESs upon which humans depend (Fu et al., 2019). Targeted sustainability activities such as land use optimization provide feasible and effective ways to manage landscape patterns and ecosystem processes and to mitigate trade-offs and enhance synergies among ESs, which finally bring win-win gains between human and nature and improve the sustainability of CHANSs.”

We will revise the beginning of Section 4.3 as: "Studies that coupled patterns and processes, and linked processes to services can reveal the interactions among social-ecological components, and help us figure out the causes of the unsustainable status of a CHANS and the corresponding solutions. Although the vegetation coverage has improved greatly and soil erosion has been well controlled in the LP after two decades of ecological restoration, some accompanied issues have started to threaten the long-term sustainability of the LP. The carbon-water conflict accompanied with revegetation is a typical example (Feng et al., 2016). Due to high-density planting, introduction of exotic plant species, and mismanagement of planted vegetation, large areas subjected to revegetation suffered soil drying (Chen et al., 2015; Wang et al., 2011). Studies have shown that the current vegetation cover has already exceeded the climate-defined equilibrium vegetation cover in many parts of the LP (Zhang et al., 2018). Considering the minimum water needed for socioeconomic activities, local revegetation in the plateau is approaching sustainable water resource limits (Feng et al., 2016), threatening the sustainability of the CHANS. In addition, although the total grain production in the LP increased because of the development of agricultural facilities and application of modern technologies (Wu et al., 2019), some counties still faced a decrease in grain production due to the conversion of cropland to forest or grassland, and further revegetation may threaten the local food supply (Chen et al., 2015). To obtain a higher yield from the declining cropland areas, local people tended to increase the use of agrochemicals to maintain or enhance land productivity (Wang et al., 2014). As a result, diffused pollution from agriculture has increased, and the quality of local land, groundwater, and surface water have been affected (Wang et al., 2014). Another important issue is the spillover effects of the LP on the telecoupled regions. In the past, the expansion of cultivation and deforestation to meet local food demand caused environmental degradation and severe soil erosion in the LP (Fu et al., 2017). The sediments produced flowed into the Yellow River, leading to the rising of riverbed levels (Chen et al., 2015) and extension of the Yellow River delta (Kong et al., 2015). After ecological restoration, the improved environment and decreased soil erosion in the LP led to the subsequent reduction of sediment load and runoff in the lower Yellow River (Wu et al., 2020). The Yellow River delta has shifted to an erosional phase (Bi et al., 2014), which might affect more than two million people and the biodiversity in distant, but coupled, ecosystems (Zhou et al., 2015). Based on a deep understanding of the ecohydrological effects caused by vegetation restoration, changes in critical ESs and their trade-off and synergy relationships, the social-ecological sustainability in the LP can be enhanced through the following targeted policies and management (Figure 3)."

Future directions of the Pattern-Process-Service-Sustainability paradigm:

**[Reviewer #3 Comment 9]** The first aspect that future research should focus on (integrated research on multiple processes) is repetitive with the "future investigation" in 4.1 (LL.208-212)

**[Response]** Thank you for your reminding. The future directions of the Pattern-Process-Service-Sustainability framework are proposed partly based on the limitation of current studies in the LP (Section 4.1). Therefore, there may be some repetitive content in these sections. We will revise the limitations in Section 4.1 as: "First, the coupling level of multiple ecological processes is still insufficient. For example, soil erosion is simultaneously affected by multiple natural and anthropogenic factors, including precipitation, terrain, soil properties, land use and land cover types, and even vegetation root traits (Zhou et al., 2016; Zhu et al., 2015). The current studies in the LP mainly coupled only two or three processes, such as precipitation and land use and land cover types (Zhou et al., 2016), which may increase the uncertainty of the results."

Conclusions:

**[Reviewer #3 Comment 10]** 393-396 is repetitive with the abstract, it's better to rephrase.

**[Response]** According to your suggestion, we will revise these sentences as: "Since 2000, the vegetation coverage in the LP has increased and soil erosion has been well controlled due to ecological restoration. However, overplanting, the introduction of exotic plant species, and the mismanagement of planted vegetation have also led to soil drying in some regions subjected to revegetation, and a trade-off between carbon sequestration and water supply has been identified at multiple scales. Some social-ecological issues, such as water resource limit, local food scarcity, and negative spillover effects, have emerged in the LP, posing a threat to its sustainable development in the future. To promote social-ecological sustainability, scientists and policy makers should pay more attention to water and food security, basin-wide governance, maintenance of ecological restoration achievements, and rural livelihood transition."

**[Reviewer #3 Comment 11]** The implication of "Pattern-Process-Service-Sustainability" paradigm should be well introduced.

**[Response]** Thank you for your suggestion. We will add the implication of our framework in the Conclusion: "A deep understanding of the reciprocal effect between landscape patterns and ecological processes, and complex linkages between ecological processes and ESs that support human well-being is crucial for promoting social-ecological sustainability. The conceptual cascade framework of "Pattern-Process-Service-Sustainability" proposed in this review can help researchers observe, analyse, and understand the dynamics of CHANSs, diagnose the causes of the unsustainable status, and support the design of policies and measures that promote sustainability."

Minor points:

1. 9: "Addressing the sustainability challenges facing humanity" is a bit strange, "Addressing the sustainability challenges that humanity is facing" sounds better?

**[Response]** We will revise the sentence accordingly.

2. 15-20 are the evaluation result of the proposed framework, but the linkage of these results is missing.

**[Response]** We will revise these sentences as: "Ecological restoration in the LP has greatly increased its vegetation coverage and controlled its soil erosion. However, some accompanied issues like soil drying in some areas due to the introduction of exotic plant species and the mismanagement of planted vegetation, and water use conflicts between vegetation and human caused by the trade-off between carbon sequestration and water supply, have started to threaten the long-term sustainability of the LP. Based on the comprehensive understanding of CHANS dynamics, the social-ecological sustainability of the LP can be improved through enhancing water and food security, implementing basin-wide governance, maintaining ecological restoration achievements, and promoting rural livelihood transition."

3. 14-15 is repetitive with LL. 68-69, at least one sentence should be deleted.

**[Response]** Following your suggestion, we will delete the sentence in the Introduction.

4. 84 the "wellbeing" should be changed as "well-being"

**[Response]** We will revise the word in the whole manuscript accordingly.

5. LL.86-87 "the same single ES" should delete "single"

**[Response]** We will delete the word accordingly.

6. 130 "soil-and water- conservation" should be "soil and water conservation"

**[Response]** We will revise the phrase accordingly.

7. L.140 "the extensive research here conducted" should be "the extensive researches conducted here"

**[Response]** We will revise the sentence accordingly.

8. L.148 "As human disturbance to .." lack of the subjective in this sentence.

**[Response]** Thank you for your suggestion. We will revise this sentence as "However, deforestation and afforestation can alter this equilibrium and cause a series of ecohydrological effects that influence water, carbon, soil processes, and the overall ecosystem sustainability (Feng et al., 2016; Zhang et al., 2018)."

9. L.195 "described in (Wang et al., 2016)" should delete "described in"

**[Response]** We will revise the sentence accordingly.

10. 236 "Using the universal soil loss equation", I guess it's USLE ( $A = R \times K \times L \times S \times C \times P$ ), it's better to show

**[Response]** We will add this equation according to your suggestion.

11. L.249 "The assessment of ESs further provide" should be "provides"

**[Response]** We will revise the sentence as: "The assessments of ESs further provide the basis for the analysis of their trade-off and synergy relationships (Figure 3)."

12. 277-278 "...the changes of demand and wellbeing of in the LP following ecological restoration" is not clear

**[Response]** We will revise this sentence as: "Second, as distant regions are connected by telecoupling processes, the use of ESs in one region may be affected by the management of ESs in other locations (Koellner et al., 2019), however, current studies mainly focus on place-based assessments of ESs, largely neglecting the flow of ESs between regions."

13. 286 "introduced exotic plant species" is better changed as "introduction of exotic plant species"

**[Response]** We will revise the phrase accordingly.

14. LL.292-293 "are needed in the ensuing ..." should be changed as "are needed for.."

**[Response]** We will revise the sentence accordingly.

15. 302 "than terrace and slope croplands have" should be "than terrace and slope croplands do"

**[Response]** Thank you for your suggestion, this sentence will be removed due to content adjustment.

16. 303 “check dams are at risk of collapse during rainstorms, due to the lack of management” please add references.

**[Response]** Thank you for your suggestion, this sentence will be removed due to content adjustment.

17. 320 “had also positive” should be “also had”

**[Response]** Thank you for your suggestion, this sentence will be removed due to content adjustment.

18. L.365 “human-wellbeing” should be “human well-being”

**[Response]** We will revise the word in the whole manuscript accordingly.

19. 380 “field monitoring, control experiments... to understand ecological processes” should add reference

**[Response]** We will revise the sentence as: “Field monitoring, control experiments, and remote sensing of natural systems at multiple scales provide abundant datasets to understand ecological processes (Wei et al., 2010; Feng et al., 2010; Yao et al., 2012; Zhou et al., 2016; Liang et al., 2018), while the development of information technology and big data can help detect human activities and strengthen the spatiotemporal links between socioeconomic and natural processes.”

20. Figure 1: The green color for describing “pattern” is improper in (b), or the transparency of background color is needed. The “sustainability” in the framework also can be shown in diagram (b).

**[Response]** Thank you for your suggestion. We will change the font color in 1b. In addition, we will merge 1a and 1b into one figure, and add an arrow from “Sustainability” to “Human and natural systems” in Figure 1.

21. Figure 2: The label of “Yellow River” is barely seen, the color of the label should be changed.

What does the white color (the western LP) indicate regrading NDVI index?

**[Response]** Thank you for your suggestion. We will change the label of “Yellow River” to dark blue. The white color represents the non-significant trend of NDVI index. We will add this in legend.

22. Figure 3: The descriptions of vegetation type is barely seen in the Figure, maybe change another color? The soil erosion, NEP change and the sediment decline are all process changes, so the subtitle of the “process change” is inappropriate

**[Response]** Thank you for your suggestion. We will move the vegetation name to the top of the image. In addition, we will delete “process change”, and named the other two processes as “Vegetation dynamics” and “Soil erosion”.