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Research article

The next step for China's national park management: Integrating ecosystem services into space boundary delimitation

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A R T I C L E I N F O

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A B S T R A C T

The contradiction between ecological conservation and economic development posed significant challenges to the management of National Parks. From the perspective of Ecological Economics, the cause of the contradiction is the difficulty of creating monetary profits from biodiversity conservation, which is the primary target of National Parks. Integrating Ecosystem Services (ESs) into space boundary delimitation is the next step in National Park management since ESs are closely related to human well-being and can provide monetary benefits. Extending the boundary of the National Park to high-ES areas and promoting ES trading can help generate funds for ecological restoration. Using the Sanjiangyuan National Park (SNP) as an example, this study proposed integrating ESs into National Park delimitation for sustainable National Park management. It was found that the current SNP boundary provides insufficient coverage of high-ES areas, while most of the multiple ES supply areas were dispersed to SNP's southeast edge. The Core conservation area showed the most prominent contradiction between ecological conservation and economic development, resulting in many low-level ES sites in the Traditional use area failing to be included in the Restoration area for protection. Future approaches would be well-advised to re-adjust SNP boundary by expanding the ES hotspot areas on the southeastern edge of SNP, as well as expanding funding sources via ecological product trade and other tools to supplement the input for ecological restoration. Overall, this study can act as a reference for optimizing National Parks within and beyond China, and promote the understanding of the Ecological Economy and sustainable development.

1. Introduction

Protected Areas (PAs) are leading in promoting ecological protection and sustainable development (Pekor et al., 2019). However, the contradiction between ecological conservation and economic development has posed significant challenges to the global management of PAs (Silva et al., 2021). The operation of PAs imposes a substantial financial burden on the government, which results in many PAs suffering funding deficits, thereby leading to many ecosystems and habitats remaining without adequate protection (Smith et al., 2021). The continuing degradation of ecosystems can significantly influence human and wildlife populations and threaten the sustainable development of the entire region (Lovejoy, 2020). Moreover a lack of capital investment could further hinder the effective monitoring of PAs, discourage the delimitation (Armsworth et al., 2011). Furthermore, the overlap of rare plant and animal habitats with local settlements and cultivated land has led to the exclusion of public infrastructure and settlements from the boundary of most PAs. Although it reduces human interference with wild animals, it also excludes potential PAs donors (Zhang et al., 2020).

Like many other countries, China's PAs face obstacles to balancing the relationship between ecological protection and economic development (Zhang et al., 2020). National Park in China is the "main body" of PAs. In 2021, at the 15th Conference of the Parties Convention on Biological Diversity (CBD-COP 15), China formally established its first five national parks, including Sanjiangyuan (SNP), Giant Panda, Siberian Tiger and Leopard, Hainan Tropical Rainforest, and Wuyi Mountain.

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However, most of China's National Parks are in impoverished areas, where the contradiction between ecological protection and economic development is highly prominent. SNP accounts for 83% of the total area of China's National Parks, and is known as the "Water Tower of Asia", with the most typical and precious ecosystem (Lu et al., 2018). All four counties within the SNP boundary are highly impoverished, and 90% of the SNP's funding comes from subsidies and provincial governments (Fu et al., 2017). The Chinese government has invested 24.4 billion yuan in building the SNP. While this facilitated progress in the rehabilitation and reconstruction of ecosystem degradation (Wu et al., 2020), many important ecosystems and habitats are still without adequate protection. Furthermore, the overlapping area between wildlife and animal husbandry is around 10,000 km^2. The environmental pollution from animal husbandry has seriously damaged the ecosystem, resulting in grassland degradation, land desertification, and soil erosion (Zhang et al., 2019a). SNP management is facing severe economic challenges.

From the perspective of Ecological Economics, sustainable National Park development should achieve ecological restoration and economic development coordination by promoting ecological product trade through ecological compensation and ecological finance (Ma et al., 2020). Currently, National Parks only take biodiversity conservation as a core value and the target for SNP delimitation (Zhang et al., 2019b). However, improving biodiversity requires the closure of SNP for conservation and cannot generate monetary value, resulting in financial shortfalls in ecological conservation within SNP (Wang, 2019). In addition, improving biodiversity relies on the government and lacks an effective mechanism for multi-stakeholder participation, thereby hindering cooperation in ecological restoration activities (Xu et al., 2019). Extending the single value of SNP is an opportunity to achieve coordination between ecological and economic development. Integrating Ecosystem Services (ESs) into the SNP delimitation is an effective mechanism. Ecosystem services (ESs) are the direct or indirect contributions of ecosystems to human welfare (TEEB, 2010). By extending the areas with high ESs levels into SNP boundary, the government can generate monetary profits through ecological product trade to supplement the huge costs of biodiversity conservation. In addition, ecological product trade involves multiple stakeholders of SNP, such as the market, government, and residents, which not only help the contradiction between the livelihood of residents and ecological protection, but also stimulate downstream stakeholders to pay for ecological protection.

The motivation for this study was to integrate ESs into National Park delimitation to coordinate ecological restoration and economic development, thereby achieving sustainable park management. Four issues need to be solved for this purpose: (1) How to identify key ESs based on multi-stakeholder interests? (2) How to evaluate the efficacy of current SNP delimitation for protecting ESs? (3) How to identify areas with high-level ESs for further adjustment of SNP delimitation? (4) How to coordinate the priority conservation objectives of each subregion in SNP to make specific boundary adjustments and management recommendations?

First, ESs selection is the basis for payments for ESs. Multi-stakeholder analysis can help reflect different stakeholder groups' preferences for specific ESs in SNP. Second, it is also essential to identify the exact locations of key ESs, which helps policymakers evaluate whether the current SNP delimitation effectively protects the ESs (Cao et al., 2020). In recent years, many ES models and simulation platforms have become more powerful and easier to use. Among them, InVEST can illustrate the ESs results spatially on a map, which has been widely used in various countries and regions (Bai et al., 2021; Fang et al., 2022a). Given that many PAs have been experiencing financial difficulties (Wu et al., 2020), identifying hotspots as a priority for expanding the SNP boundary can achieve effective protection with the limited funds available (Han et al., 2019). Finally, understanding the differences in trade-offs and synergies across ESs can help managers coordinate the relationships between the regions and functional zones of SNP, which can help restore SNP.

As SNP is more representative of natural ecology and typical of the contradiction between ecology and economy compared to other National Parks in China, we selected SNP as the study region. We found that the current SNP boundary showed insufficient coverage of high-ES areas. Expanding the SNP boundary to include ES hotspot areas on the southeastern edge outside SNP can be the most effective solution for ensuring the SNP's long-term sustainability. The overarching aim of this study was to highlight the critical role of ES in coordinating ecological conservation and economic development in National Parks. The experience of delimiting SNP can be a reference for developing National Parks within and beyond China.

2. Materials and methods

2.1. Study area

The Sanjiangyuan National Nature Reserve (SNNR) is located in the southern part of Qinghai Province, China, with a total area of 395,000 km^2 (89°45′E−102°23′E, 31°39′N-36°12′N) (Fig. 1). Of this area, the Sanjiangyuan National Park (SNP) pilot area encompasses 123,100 km^2 (increasing to 190,700 km^2 in 2021), including the source region of the Yangtze River (CJ), the source region of the Yellow River (HH), and the source region of the Lancang River (LCJ). Each region is divided into three functional areas, including the core conservation area (c), ecological restoration area (e), and traditional utilization area (t). SNP comprises 31.20% of the total area of the SNNR, while the region outside SNP (Outside) covers an area of 271,900 km^2, and accounts for 68.80%.

The SNNR is located at the northern end of the Qinghai-Tibet Plateau climate zone, with a typical plateau climate of wet, warm summers and dry, cold winters. In high-altitude areas, situated more than 5000 m above sea level, the annual temperature is around −5.6 °C. In low-altitude areas, located above 2000 m above sea level, the annual temperature is around 7.8 °C. Annual rainfall varies from approximately 262.2 mm in the West to around 772.8 mm in the East. Annual solar radiation ranges from 5.658 to 6.469 MJ/m^2. Because the base year for the latest Sanjiangyuan National Park master plan is 2015, this was used as the benchmark year to describe the current situation.

2.2. Analytical framework

This study develops a framework for integrating ESs into National Park delimitation to coordinate ecological restoration and economic development (Fig. 2). The framework consists of five stages: (1) identifying and estimating key ESs to be evaluated, which should reflect the interests of the relevant stakeholder groups in the study area; (2) comparing ES levels within and outside SNP boundary to evaluate the efficacy of current SNP boundary in protecting ES; (3) identifying multiple ES hotspot areas to determine areas that should be prioritized for expansion into SNP boundary; (4) analyzing the trade-off/synergistic relationship between ESs in different regions to determine the priority conservation objectives in each region; (5) applying the results to propose effective SNP boundary adjustments and differentiated management recommendations.

2.2.1. Key ESs selection and calculation

We used stakeholder analysis to identify and select relevant ESs, considering ES consumption, policy relevance, and data availability. According to the local industrial structure, three main stakeholders were considered: local herdsmen (residents), local governments (experts), and downstream government representatives, whose different interests led them to focus on different ESs (Table 1). At present, the delimitation and functional zoning of SNP only consider three ESs, namely water retention (WR), sediment retention (SDR), and carbon storage (CS). Due to the critical role of the SNP in providing high-quality freshwater for downstream areas and protecting local habitats, the present study added water yield (WY), nutrient export (NDR), and habitat quality (HQ) to the

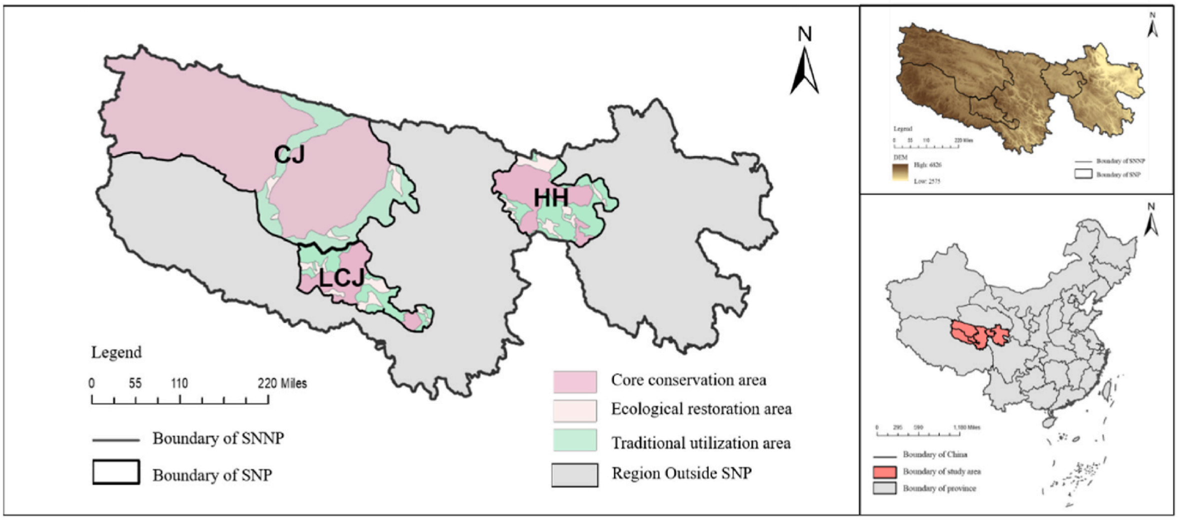

Fig. 1. Maps showing the location and functional areas of the Sanjiangyuan National Park in China.

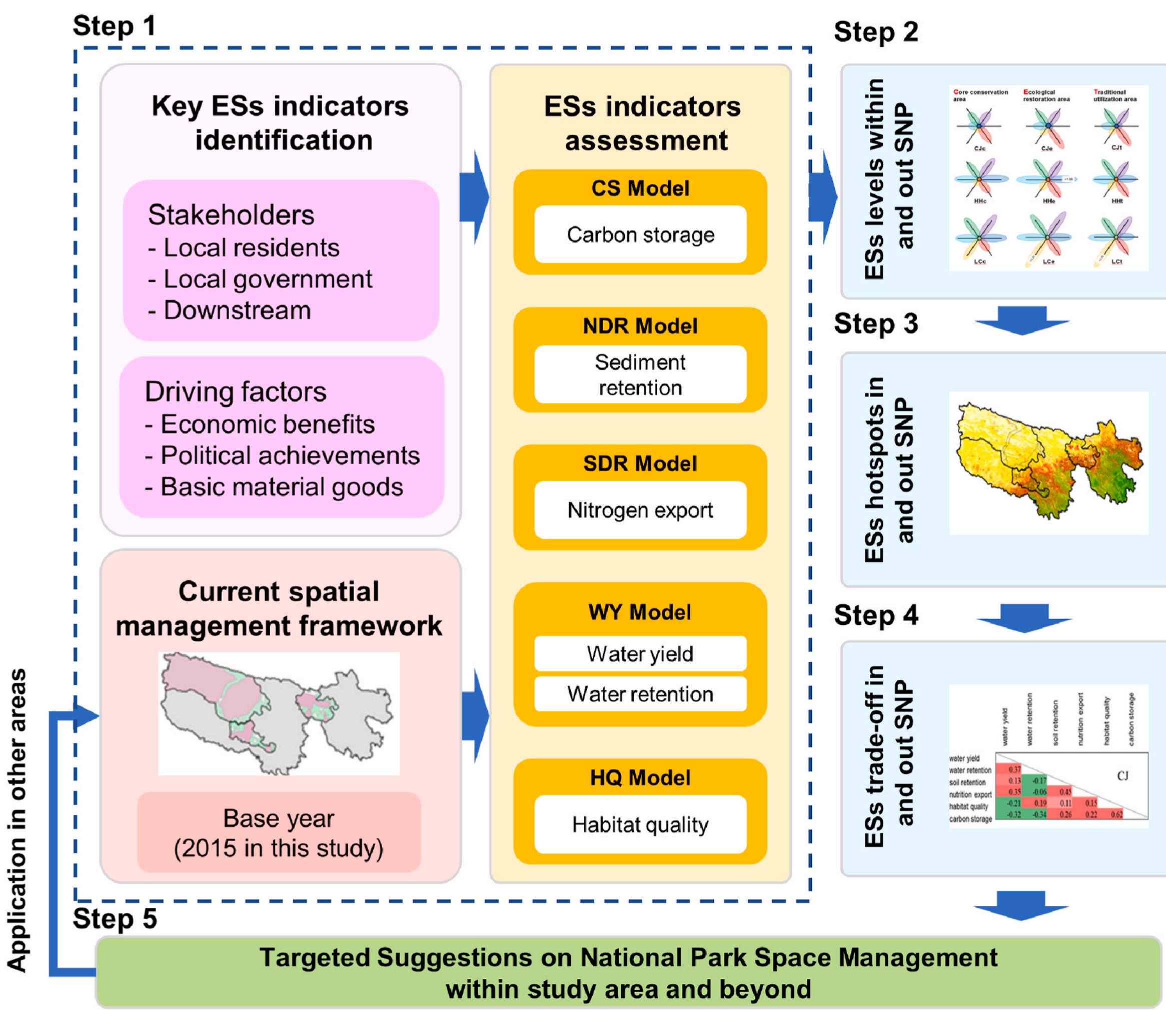

Fig. 2. The analytical framework used for integrating ESs into Sanjiangyuan National Park delimitation.

analysis.

Six InVEST models were used to quantify ESs. Details of all sub-models and the calculation process for each ES can be found in SI (Part 2). Tables S4–S7 in the Supplementary Information (SI) lists the key parameters and the biophysical table required by the InVEST model. All the essential input parameters for the InVEST model and the ES results were validated with relevant literature and measured hydrological data. For the CS model, mean values from other studies in China were used for

Table 1
ESs selection based on analysis of multiple stakeholders.

Stakeholders	Goals	ESs concerned
Residents (Herders)	Develop livestock husbandry to maximise economic benefits.	☐ **Nutrient supply:** Higher nutrient supply leads to better plant yield and more economic benefits for herders. Herders use chemical fertilizers to improve nutrient supply artificially, but this reduces the water quality and presents a clear trade-off for downstream residents. ☐ **Soil conservation:** Soil loss accelerates high levels of nutrient outflow.
Government (experts)	Political achievements: ensure ecological health and balanced regional development. (Experts are often invited to be participants in government environmental protection project planning.)	☐ **Carbon storage:** The forest in SNP has a substantial carbon storage capacity, laying solid foundations for the realization of the Chinese government's "dual carbon goal". ☐ **Water retention:** SNP is a key ecological function area for water conservation in China. ☐ **Soil conservation:** Key assessment indicator of regional ecological protection. ☐ **Habitat quality:** directly related to the habitat security of many endangered wild animals.
Downstream stakeholder representatives	Access to sufficient clean water.	☐ **Water yield:** closely related to the available surface water for about 1 billion residents downstream. ☐ **Water purification:** has a direct impact on the water quality of residents and is therefore closely related to their health.

verification. In contrast, other studies' mean values and ranges in the Sanjiangyuan National Nature Reserve (SNNR) were used to validate the SDR, WY, and HQ models. For the NDR model, observation data from hydrological stations were used. The simulation results all met the research requirements. For detailed information about the parameterization and verification of the InVEST model, see SI (Part 2).

2.2.2. *Differences in ESs within and out SNP boundary*

To compare ES levels within and outside the SNP boundary for evaluating the efficacy of current SNP boundary in protecting ES, we used the Analysis of variance (ANOVA) to test the statistical differences in ES supply in four different regions and three functional areas. The ArcGIS random point tool was used to sample the ES values in different regions in 2015. The sampling point distance was set to 10 km, and a total of 44,662 samples were randomly selected. The number of sampling points in each region and each functional area is shown in Table S7.

2.2.3. *Identification of hotspot areas*

To identify priority areas for future expansion into the SNP boundary, we used spatial overlay analysis to identify multiple ES hotspot areas. According to the biophysical processes of ES supply, flow, and demand, the sources of ES supply, which are the multifunctional hotspots, are the areas of the highest ecosystem value (Schirpke et al., 2019). Following previous research (Liu et al., 2019), we extracted the top 50% of areas of value for each ES, considering them to be the "hotspot" of the service. We overlaid these areas to ascertain the distribution of multifunctional ES hotspots in SNNR. Where ES values exceeded their average by a particular grid unit, the area was defined as an n-type (n = 1,2,3,4,5,6) ES hotspot, and otherwise as a 0-type ES hotspot. In this study, an area was regarded as a multiple ES supply area if it was found to provide four or more ESs simultaneously. In the future, these areas should be recognized as priority areas for conservation under the constraints of financial and material resources.

2.2.4. *Quantification of trade-offs and synergies*

To determine the priority conservation targets for each region, we used the Spearman rank correlation coefficient, commonly used in trade-off collaborative research, to evaluate ES trade-offs and synergies within and outside SNP. If the coefficient is positive at a 5% level of significance, then a relationship of synergy occurs between the two services. This indicates that when the supply of one service increases, the supply of the other also increases. Conversely, a negative coefficient implies the occurrence of a significant trade-off relationship between the two services. To improve management efficiency, we will prioritize the protection of ESs with higher synergies (Sylla et al., 2020). ArcGIS random point tools collected large quantities of samples (44,662 random points). This large sample size gives us confidence in the reliability of the results, although it may lead to increased significant effects (Cord et al., 2017; Sylla et al., 2020).

3. Results

3.1. *ES levels within and outside SNP*

Comparing ES supply levels within and outside the SNP boundary, it was found that ESs were significantly greater outside SNP than inside, with NDR, HQ, WR, and SDR outside being more than double the values inside SNP (Fig. 3). Within SNP, ES levels were lowest in CJ, especially WR (1.06 mm) and SDR (2.75 t/ha), which equated to 12.96% and 20.00%, respectively, of the mean value for the SNNR. WR (13.33 mm) was higher in HH than in CJ and LCJ, while SDR (4.33 t/ha) was well below the mean value for SNNR (21.27 t/ha). NDR (0.72 kg/ha) was lowest in HH, indicating that this region possessed the highest water purification capacity. LCJ had the highest values for CS (82.84 t/ha) and HQ (0.93).

Among the three functional areas (Fig. 3), the Core conservation area, the primary habitat of rare plants and animals and the source of rivers and lakes, was found to have the highest WR and water purification capacity, while other ESs were lower. ESs in Ecological restoration areas and Traditional utilization areas were relatively high. In CJ, although CJc revealed the highest WR (1.06 mm) and water purification capacity, the remaining four ESs were the lowest among the three functional areas and were significantly lower than the benchmark. CJe had the highest NDR (1.01 kg/ha) among the three functional zones. HHc had the highest HQ (0.81) in HH, slightly higher than the benchmark (0.79). The remaining ESs in HHc were significantly lower than in the other two functional areas, especially SDR (2.93 t/ha in HHc, 5.41 t/ha in HHe, and 5.55 t/ha in HHt), which was less than half of the benchmark. Similarly to CJc, LCJc had the highest WR (9.83 mm) and the lowest NDR (3.02 kg/ha). ESs in LCJe were also high, among which HQ had the most significant value in the entire study region (0.96).

3.2. Distribution of multifunctional ES hotspots

Identifying the spatial distribution of the multifunctional hotspots, it was found that the 0–6 type ES hotspots showed an increasing trend from northwest to southeast in SNNR (Fig. 4a). Similar trends were found for the three ESs in the previous evaluation system (Fig. 4b). Comparing the percentage of multifunctional hotspots within and outside SNP (Fig. 4c), we observed that multiple ES supply areas were dispersed outside SNP, where grids with the ability to provide four or more ESs accounted for 49.59% of the total area. Almost all of the 6-type ES hotspots in the SNNR were concentrated at the southeastern edge of the region. Inside SNP, 2-type ES hotspots occupied the largest proportion, with 47.15% of the total area in CJ. The second most significant proportion was the 0-type ES hotspot, accounting for 37.39% of the entire area. In addition, 5-type and 6-type hotspots were almost entirely absent. HH was dominated by 2-type and 4-type ES hotspots, with an apparent dividing line between them, and LCJ was dominated by 4-type and 5-type ES hotspots, with a similar dividing line. Among the three types of functional areas, the Core conservation area had the lowest percentage of multifunctional hotspots compared to the Ecological conservation areas and Traditional utilization areas.

3.3. Variations in trade-offs/synergies among functional zones

Comparing ES relationships within and outside SNP, it was found that ESs outside SNP all presented synergistic relationships. In contrast, the ES relationship inside the SNP varied in both regions and functional areas (Fig. 5). In CJ, WR and SDR, which were significantly lower than the benchmark, exhibited a trade-off relationship (−0.17), as did WY and CS, and WY and HQ. The trade-off coefficient in CJe (−0.70, −0.54) was higher than that of CJc and CJt, indicating that, although grassland restoration in CJe can improve habitat quality and carbon sequestration capacity, it may adversely affect the availability of surface water in downstream areas. In HH, SDR and NDR, being significantly lower than the benchmark, showed a strong synergistic relationship (0.45), while SDR and WR were found to have a trade-off relationship (−0.27). The trade-off relationships were most evident in HHc, where SDR was lowest (−0.41), suggesting that to improve the SDR in HH, attention should be paid to local water conservation and downstream water quality issues. In LCJ, the synergy of WY, SDR, and NDR was higher than that of CJ and HH.

4. Discussion

4.1. Insufficient coverage of high-ES area

We evaluated the efficacy of delimitation of SNP for protecting ESs. Our results indicated that the current SNP boundary exhibited insufficient coverage of the high-ES area. For example, we showed that the SNP boundary was in the northwestern part of the SNNR. Still, all six ESs showed a gradually increasing trend from the northwest to the southeast of the SNNR (Fig. S2). The overall ES level outside SNP was significantly higher than inside (Fig. 3). Almost all of the multiple ES supply areas were dispersed on the southeast edge outside SNP. However, these regions have never been covered in the Core conservation areas defined by previous revisions of SNP spatial planning. The difference in ES levels within and outside SNP could be attributed to the higher vegetation

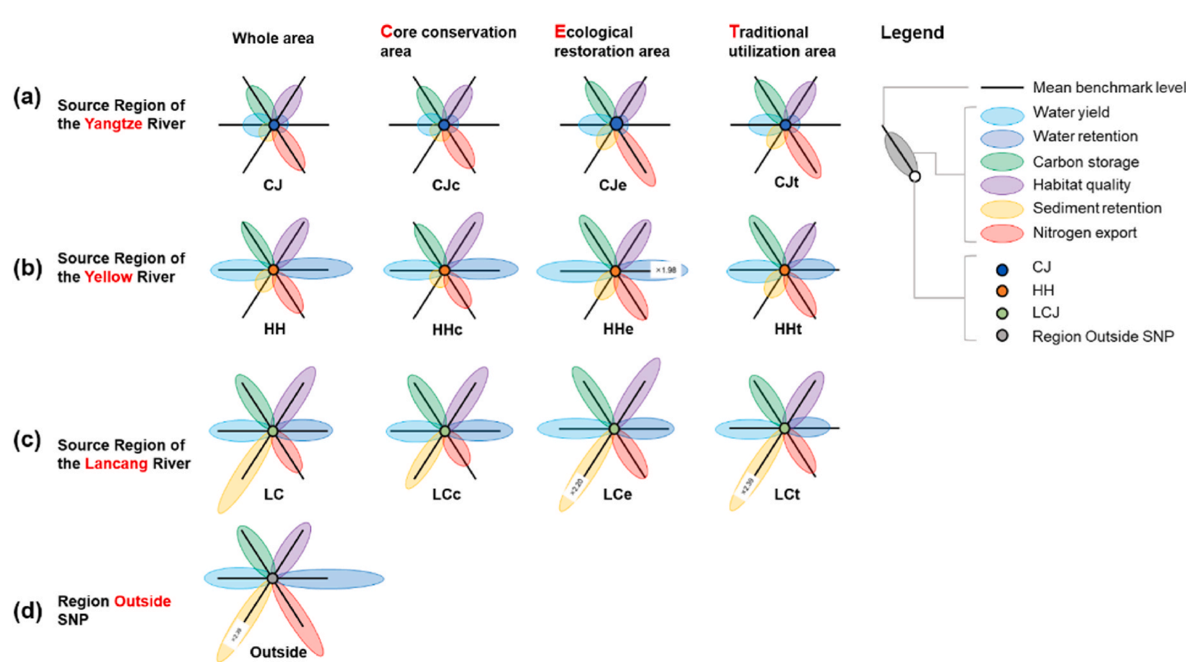

Fig. 3. (a–d). ESs supplied by the 13 functional zones (n = 44,662) in the Sanjiangyuan National Reserve in 2015, were divided into four major types based on regions (Note: The color of the center point represents the different regions inside and outside SNP. The color of the leaves represents the different types of ES, and the size of the leaves represents the level of ES relative to the overall SNNR benchmark).

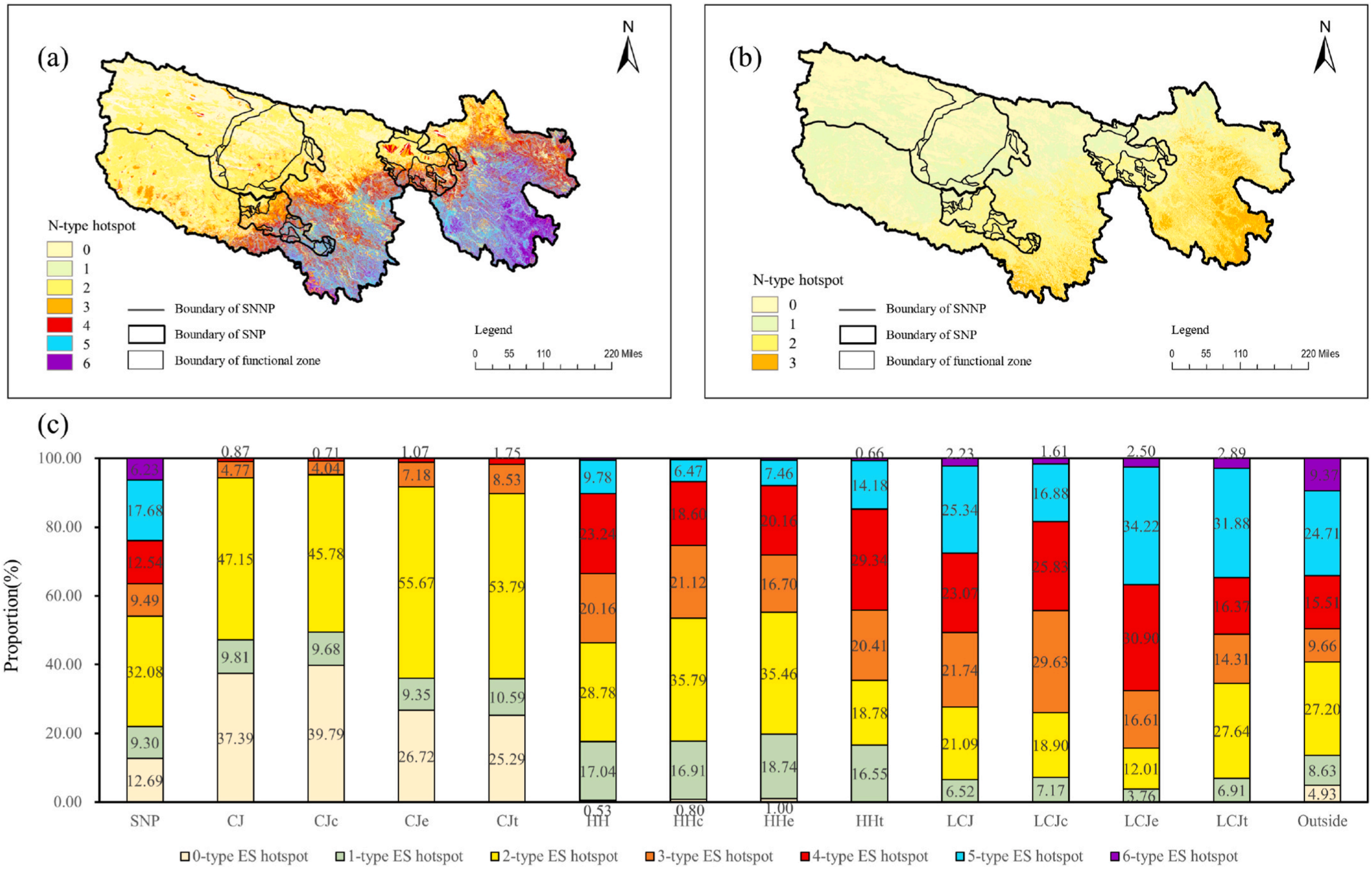

Fig. 4. (a) Hotspot distribution of the provision of six ESs in the Sanjiangyuan National Nature Reserve. (b) The distribution of Hotspots of three ESs in the previous evaluation system in the Sanjiangyuan National Nature Reserve. (c) Hotspot percentage distribution of ES supply among functional zones in the Sanjiangyuan National Nature Reserve.

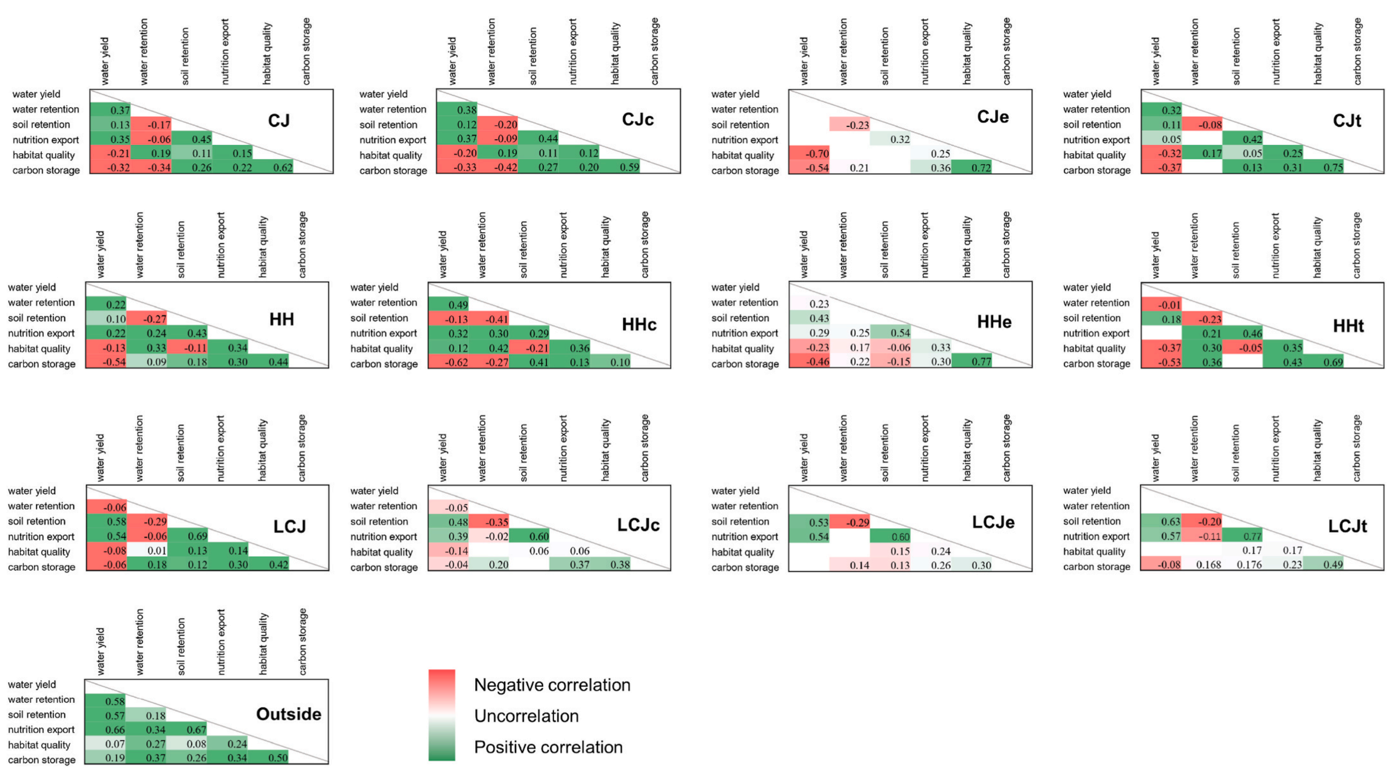

Fig. 5. Spearman correlation results for the ecological indicators of each functional area (n = 44,662, p < .05).

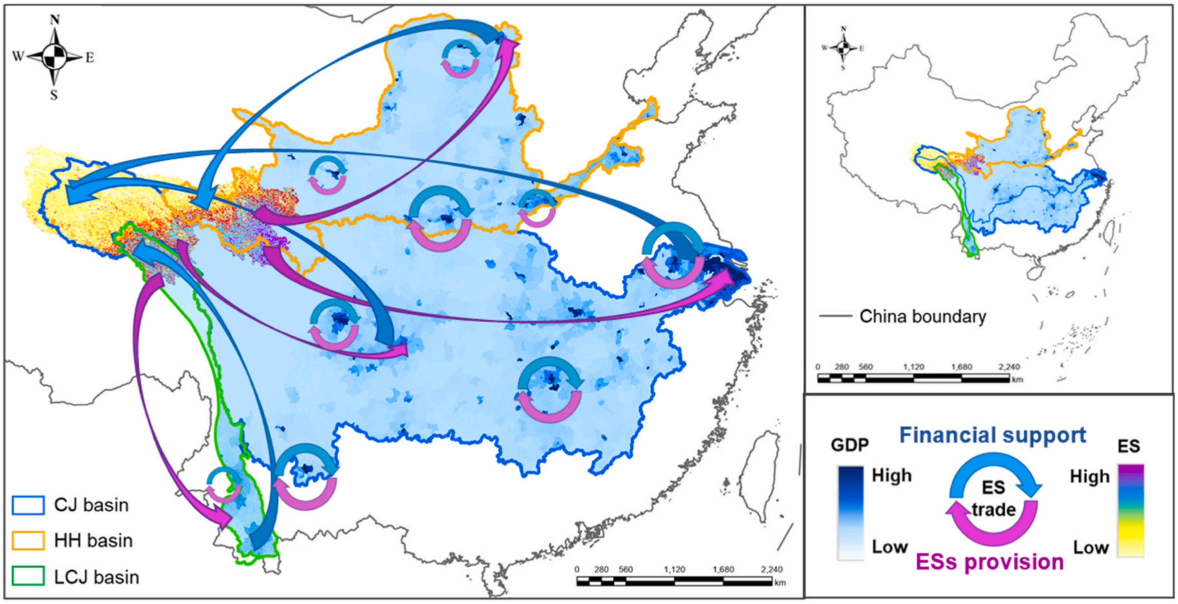

Fig. 6. A sketch of ESs and economic value trade between Sanjiangyuan National Park and downstream areas. (CJ basin refers to Changjiang basin; HH basin refers to Huanghe basin; LCJ basin refers to Lancangjiang basin).

coverage on the southeastern edge (details can be found in SI Part 3). However, past human interference has led to the migration of rare species to the northwestern part with poorer ecosystems (Zhang et al., 2019b).

Among three functional areas, we found that the Core conservation area showed the most prominent contradiction between ecological conservation and economic development. Most ESs in the Core conservation area were significantly lower than in other functional areas (Fig. 3). The proportion of supply areas that could provide multiple ESs was also lowest here. This indicates that while the potential to generate monetary profits by ES valuation in Core conservation area is relatively low, the area is the largest and most important for biodiversity conservation (Xiao et al., 2016). It requires sufficient investment, significantly reducing the funding visibility of other functional areas (Tang, 2020). We found many low-level ES areas in the Traditional use area that need to be included in the Restoration area for conservation; the lack of funding has led to a vicious circle of ecological deterioration and infertility in Ecological restoration areas and Traditional utilization areas.

4.2. Suggestions for SNP boundary adjustments and ES enhancement

The Chinese government is already aware of the problems of PAs delimitation and is actively promoting the adjustment of PAs, with the National Park as the "main body" (Zhang et al., 2019b). However, the current SNP boundary shows insufficient coverage of the high-ES area. To overcome these issues, we propose suggestions for further adjustments to SNP delimitation. The results can be used for the PA's adjustment, and provide a reference for other PAs at home and abroad.

On the one hand, the boundary of SNP should be expanded to the southeast edge of the outside region, where the ecosystem is relatively stable. In 2021, China included certain ES hotspots in its SNP, indicating that the government has started emphasizing ES conservation (Han et al., 2019). However, due to financial constraints, the remaining hotspot areas have yet to be included within the SNP boundary. On the other hand, within the SNP, given that almost all ESs in CJ are at low levels, the CJc should be expanded to enhance ES. In CJc, it is recommended that glaciers, lakes, and wetlands are closed for conservation to strengthen WR. Control of desertification is imperative if we are to ensure the health of alpine grasslands and desert ecosystems, thereby improving SDR (Liu et al., 2019). In CJe, high-coverage grasslands should be adjusted to CJc for closed management, allowing for ecological restoration. For CJt, severely and moderately degraded parts of sandy land and Gobi should be adjusted to CJe.

The critical task in HH is to raise the level of SDR. The most effective means of doing so would be to expand the area of meadows and grasslands while maintaining existing wetlands and vegetation (Andrade et al., 2020). For HHc, there is an urgent need to protect the authenticity and integrity of the plateau lakes' natural landscape and accelerate grassland restoration to control soil erosion. For HHe, management strategies should seek to reinforce the supervision of grassland and meadow ecosystems, focusing on preventing the further destruction of medium-covered grasslands. In HHt, black soil and sandy land should be re-classified into HHe, thereby accelerating the restoration process. Other recommendations include maintaining appropriate ES levels in LCJ, adjusting the 4-type and 5-type ES hotspots into LCJc, and carrying out typical Lancang River Basin ecological management projects to completion.

4.3. Integrating ES is the next step for national park management

ESs provided by ecosystems in National Parks are becoming increasingly scarce (Farley and Kish, 2021). Therefore, we integrate ESs into National Park delimitation in order to transform the ecological advantages of National Parks into economic growth. By expanding the SNP boundary to include high-ES areas, the SNP can obtain financial support for ecological restoration by promoting ES trade with downstream areas (Wang et al., 2021). Specifically, SNP provides ESs to the downstream through ecological protection, while the downstream pays for the ESs through monetary values (Fig. 6). The improvement of ESs also helps to improve the living environment of local plants and animals in SNP, which is beneficial to the conservation of biodiversity (Lu et al., 2020), thereby achieving a win-win scenario for both ecology and the economy.

Such cross-regional trades, even though they rely on further research on ES flows and ES value (Fang et al., 2022b; Wang et al., 2022), are being promoted in China. As the "Water Tower of Asia", there is a strong demand from downstream for its WY and water purification services provided by SNP (Su et al., 2021). There has been much progress in trading these two ESs in China, for example, in water rights trading and emission permit trading (Fang et al., 2021; Tian et al., 2020). However, HQ, SDR, and WR are examples of public goods that are difficult to trade in the market (Ma et al., 2020). For instance, we found that the SDR in HH is relatively low, but SDR is a public good that is difficult to trade, like WY and water purification services. Concerning China's "Three Gorges Fund," "Xin'anjiang Basin Fund" (Jiang et al., 2021), and other effective practices (Fang et al., 2021), the government should set up a special fund and establish a reasonable ecological compensation standard for the enhancement of SDR in HH. We also found that HQ showed a trade-off relationship with WY and SDR in Core conservation areas (Fig. 5). Considering the unique function of Core conservation areas for biodiversity conservation, emphasis should be on enhancing ESs in traditionally areas used for further development of carbon emissions trading and water rights trading, thereby supplementing ecological conservation investments in Core conservation areas.

4.4. Limitations and future research

The trade-offs and synergies between ESs exhibit distinct and complex scale effects (Bai et al., 2020). Previous studies have demonstrated that scale leads to trade-off relationships between ESs, changing at different time and space scales (Liu et al., 2019). In this study, we considered the trade-offs of ESs at the scale of regional and functional zones, and future research may delve further into the comparison of multi-scale trade-offs. In addition, the causes of the trade-offs and synergies acknowledged in this paper have not yet been investigated. The mutual verification of different research results would be particularly worthy of further analysis. Studies have revealed, for instance, that SDR is closely related to the existing above-ground biomass of vegetation (Rajbanshi and Bhattacharya, 2020). Due to the large quantities of plateau deserts, alpine wetlands, and snow-capped glaciers in SNNR, the relationship between WR and SDR may differ in other regions. In addition, when performing trade-off/synergy analysis, a larger sample size was selected for this study to ensure the sample's representativeness, which may improve the significance of the results.

This study found that hotspot types were closely related to altitude in the SNNR. LULC and climate types varied at different altitude levels, suggesting that altitude should be adequately considered during functional zoning. Future research should focus on the impact of altitude and climate-related vegetation types on ES functions and propose targeted suggestions for further vegetation protection in SNP. Although the study region of this article is SNP, the research framework could be applied to other national parks in China for comparison or verification. Future studies should also seek to provide a basis upon which decisions can be made regarding future ecological protection, through multi-year data comparison analysis or the simulation of future land use pattern changes in different scenarios, thus enabling practical countermeasures and suggestions to be formulated. Our framework, based on the InVEST model and combined with spatial statistical methods, can be applied in other countries, since the InVEST model is used worldwide. In this study, six key ESs were selected by combining the characteristics of SNP and multi-stakeholder preferences, and the selection of ESs may differ in other National Parks.

5. Conclusion

This study proposed integrating ESs into space boundary delimitation to coordinate ecological restoration and economic development in National parks. It was found that the current SNP boundary showed insufficient coverage of high-ES area, while almost all of the multiple ES supply areas were dispersed on the southeast edge outside SNP. The Core conservation area showed the most prominent contradiction between ecological conservation and economic development. It has the most significant area among the three functional areas but has the lowest potential to develop the ES trade, resulting in an increased financial burden on the government. It is suggested that the boundary of SNP should be expanded to the southeast edge of the outside region, where the ecosystem is relatively stable. In this way, SNP can obtain financial support for ecological restoration by promoting ES trading with downstream areas. Given that almost all ESs in CJ are at low levels, the CJc should be expanded to enhance ES. In HH, black soil and sandy land should be reclassified into HHe, thereby improving SDR. The 4-type and 5-type ES hotspots in LCJ should be adjusted into LCJc to maintain high ES levels. With these changes, SNP can be a reference for delimitation in other PAs within and beyond China.

Credit author statement

Shi Xue and **Zhou Fang**: Data curation; Formal analysis; Roles/Writing – original draft; Writing – review & editing, **Yang Bai**: Conceptualization; Funding acquisition; Supervision; Validation; Roles/Writing – original draft; Writing – review & editing, **Juha M. Alatalo**: Roles/Writing – original draft; Writing – review & editing, **Yang Yang** and **Fan Zhang**: Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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References

Andrade, E.M., Guerreiro, M.J.S., Palácio, H.A.Q., Campos, D.A., 2020. Ecohydrology in a Brazilian tropical dry forest: thinned vegetation impact on hydrological functions and ecosystem services. J. Hydrol.: Reg. Stud. 27, 100649 https://doi.org/10.1016/j.ejrh.2019.100649.

Armsworth, P.R., Cantú-Salazar, L., Parnell, M., Davies, Z.G., Stoneman, R., 2011. Management costs for small protected areas and economies of scale in habitat conservation. Biol. Conserv. 144, 423–429. https://doi.org/10.1016/j.biocon.2010.09.026.

Bai, Y., Chen, Y., Alatalo, J.M., Yang, Z., Jiang, B., 2020. Scale effects on the relationships between land characteristics and ecosystem services- a case study in Taihu Lake Basin, China. Sci. Total Environ. 716, 137083 https://doi.org/10.1016/j.scitotenv.2020.137083.

Bai, Y., Fang, Z., Hughes, A.C., 2021. Ecological redlines provide a mechanism to maximize conservation gains in Mainland Southeast Asia. One Earth 4, 1491–1504. https://doi.org/10.1016/j.oneear.2021.09.010.

Cao, Y., Cao, Y., Li, G., Tian, Y., Fang, X., Li, Y., Tan, Y., 2020. Linking ecosystem services trade-offs, bundles and hotspot identification with cropland management in the coastal Hangzhou Bay area of China. Land Use Pol. 97, 1–11.

Cord, A.F., Bartkowski, B., Beckmann, M., Dittrich, A., Hermans-Neumann, K., Kaim, A., Lienhoop, N., Locher-Krause, K., Priess, J., Schröter-Schlaack, C., Schwarz, N., Seppelt, R., Strauch, M., Václavík, T., Volk, M., 2017. Towards systematic analyses of ecosystem service trade-offs and synergies: main concepts, methods and the road ahead. Ecosystem Services, SI:Servicing ES-EcoSummit16 28, 264–272. https://doi.org/10.1016/j.ecoser.2017.07.012.

Fang, Z., Chen, J., Liu, G., Wang, H., Alatalo, J.M., Yang, Z., Mu, E., Bai, Y., 2021. Framework of basin eco-compensation standard valuation for cross-regional water supply – a case study in northern China. J. Clean. Prod. 279, 123630 https://doi.org/10.1016/j.jclepro.2020.123630.

Fang, Z., Wang, H., Bai, Y., Campos-Arceiz, A., Liu, G., Jiang, B., 2022a. Framework for a more balanced consideration of hydropower development through ecosystem services assessment. Sustain. Prod. Consum. 33, 557–566. https://doi.org/10.1016/j.spc.2022.07.027.

Fang, Z., Wang, H., Xue, S., Zhang, F., Wang, Y., Yang, S., Zhou, Q., Cheng, C., Zhong, Y., Yang, Y., Liu, G., Chen, J., Qiu, L., Zhi, Y., 2022b. A comprehensive framework for detecting economic growth expenses under ecological economics principles in China. Sustain. Horizons 4, 100035. https://doi.org/10.1016/j.horiz.2022.100035.

Farley, J., Kish, K., 2021. Ecological economics: the next 30 years. Ecol. Econ. 190, 107211 https://doi.org/10.1016/j.ecolecon.2021.107211.

Fu, M., Tian, J., Zhu, Y., Tian, Y., Zhao, Z., Li, J., 2017. Identification of functional zones and methods of target management in Sanjiangyuan National Park. Biodivers. Sci. 25, 71. https://doi.org/10.17520/biods.2016098.

Han, Y., Dong, S., Wu, X., Liu, S., Su, X., Zhang, Y., Zhao, H., Zhang, X., Swift, D., 2019. Integrated modeling to identify priority areas for the conservation of the endangered plant species in headwater areas of Asia. Ecol. Indicat. 105, 47–56. https://doi.org/10.1016/j.ecolind.2019.05.064.

Jiang, X., Eaton, S., Kostka, G., 2021. Not at the table but stuck paying the bill: perceptions of injustice in China's Xin'anjiang eco-compensation program. J. Environ. Pol. Plann. 1–17. https://doi.org/10.1080/1523908X.2021.2008233.

Liu, L., Zhang, H., Gao, Y., Zhu, W., Liu, X., Xu, Q., 2019. Hotspot identification and interaction analyses of the provisioning of multiple ecosystem services: case study of Shaanxi Province, China. Ecol. Indicat. 107, 105566 https://doi.org/10.1016/j.ecolind.2019.105566.

Lovejoy, T.E., 2020. Biodiversity conservation targets: How to allocate resources. One Earth 2, 415–416. https://doi.org/10.1016/j.oneear.2020.05.003.

Lu, C., Chai, J., Murphy, R.W., Che, J., 2020. Giant salamanders: farmed yet endangered. Science 367, 989. https://doi.org/10.1126/science.abb2375, 989.

Lu, W., Wang, W., Shao, Q., Yu, Z., Hao, Z., Xing, W., Yong, B., Li, J., 2018. Hydrological projections of future climate change over the source region of Yellow River and Yangtze River in the Tibetan Plateau: a comprehensive assessment by coupling RegCM4 and VIC model. Hydrol. Process. 32, 2096–2117. https://doi.org/10.1002/hyp.13145.

Ma, G., Wang, J., Fang, Yu, Yang, Weishan, Ning, J., Peng, F., Zhou, Xiafei, Zhou, Ying, Cao, D., 2020. Framework construction and application of China's Gross Economic-Ecological Product accounting. J. Environ. Manag. 264, 109852 https://doi.org/10.1016/j.jenvman.2019.109852.

Pekor, A., Miller, J.R.B., Flyman, M.V., Kasiki, S., Kesch, M.K., Miller, S.M., Uiseb, K., van der Merve, V., Lindsey, P.A., 2019. Fencing Africa's protected areas: costs, benefits, and management issues. Biol. Conserv. 229, 67–75. https://doi.org/10.1016/j.biocon.2018.10.030.

Rajbanshi, J., Bhattacharya, S., 2020. Assessment of soil erosion, sediment yield and basin specific controlling factors using RUSLE-SDR and PLSR approach in Konar river basin, India. J. Hydrol. 587, 124935 https://doi.org/10.1016/j.jhydrol.2020.124935.

Schirpke, U., Candiago, S., Egarter Vigl, L., Jäger, H., Labadini, A., Marsoner, T., Meisch, C., Tasser, E., Tappeiner, U., 2019. Integrating supply, flow and demand to enhance the understanding of interactions among multiple ecosystem services. Sci. Total Environ. 651, 928–941. https://doi.org/10.1016/j.scitotenv.2018.09.235.

Silva, J.M.C. da, Dias, T.C.A., de, C., Cunha, A.C. da, Cunha, H.F.A., 2021. Funding deficits of protected areas in Brazil. Land Use Pol. 100, 104926 https://doi.org/10.1016/j.landusepol.2020.104926.

Smith, M.K.S., Smit, I.P.J., Swemmer, L.K., Mokhatla, M.M., Freitag, S., Roux, D.J., Dziba, L., 2021. Sustainability of protected areas: vulnerabilities and opportunities as revealed by COVID-19 in a national park management agency. Biol. Conserv. 255, 108985 https://doi.org/10.1016/j.biocon.2021.108985.

Su, H., Wang, N., Su, Y., 2021. 1. Management world journal press, development research center of the state council, beijing 1000262. Project management center for conversion of farmland to forests and grasses, national forestry and grassland administration, beijing 100714. The experience and its reference study of law enforcement system of Sanjiangyuan National Park pilot. Biodiversity Science 29, 304–306. https://doi.org/10.17520/biods.2021047.

Sylla, M., Hagemann, N., Szewrański, S., 2020. Mapping trade-offs and synergies among peri-urban ecosystem services to address spatial policy. Environ. Sci. Pol. 112, 79–90. https://doi.org/10.1016/j.envsci.2020.06.002.

Tang, X., 2020. The establishment of national park system: a new milestone for the field of nature conservation in China. Int. J. Geoheritage and Parks 8, 195–202. https://doi.org/10.1016/j.ijgeop.2020.11.006.

TEEB, 2010. The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations.

Tian, G., Liu, J., Li, X., Li, Y., Yin, H., 2020. Water rights trading: a new approach to dealing with trans-boundary water conflicts in river basins. Water Pol. 22, 133–152. https://doi.org/10.2166/wp.2020.180.

Wang, J., Yu, F., Ma, G., Peng, F., Zhou, X., Wu, C., Yang, W., Wang, C., Cao, D., Jiang, H., Jing, H., Qu, S., Xu, M., 2021. Gross economic-ecological product as an integrated measure for ecological service and economic products. Resour. Conserv. Recycl. 171, 105566 https://doi.org/10.1016/j.resconrec.2021.105566.

Wang, J.-H.Z., 2019. National parks in China: parks for people or for the nation? Land Use Pol. 81, 825–833. https://doi.org/10.1016/j.landusepol.2018.10.034.

Wang, L., Zheng, H., Chen, Y., Ouyang, Z., Hu, X., 2022. Systematic review of ecosystem services flow measurement: main concepts, methods, applications and future directions. Ecosyst. Serv. 58, 101479 https://doi.org/10.1016/j.ecoser.2022.101479.

Wu, J., Wu, G., Zheng, T., Zhang, X., Zhou, K., 2020. Value capture mechanisms, transaction costs, and heritage conservation: a case study of Sanjiangyuan National Park, China. Land Use Pol. 90, 104246 https://doi.org/10.1016/j.landusepol.2019.104246.

Xiao, Yang, Ouyang, Z., Xu, W., Xiao, Yi, Zheng, H., Xian, C., 2016. Optimizing hotspot areas for ecological planning and management based on biodiversity and ecosystem services. Chin. Geogr. Sci. 26, 256–269. https://doi.org/10.1007/s11769-016-0803-4.

Xu, W., Pimm, S.L., Du, A., Su, Y., Fan, X., An, L., Liu, J., Ouyang, Z., 2019. Transforming protected area management in China. Trends Ecol. Evol. 34, 762–766. https://doi.org/10.1016/j.tree.2019.05.009.

Zhang, J., Jiang, F., Li, G., Qin, W., Li, S., Gao, H., Cai, Z., Lin, G., Zhang, T., 2019a. Maxent modeling for predicting the spatial distribution of three raptors in the Sanjiangyuan National Park, China. Ecol. Evol. 9, 6643–6654. https://doi.org/10.1002/ece3.5243.

Zhang, J., Jiang, F., Li, G., Qin, W., Li, S., Gao, H., Cai, Z., Lin, G., Zhang, T., 2019b. Maxent modeling for predicting the spatial distribution of three raptors in the Sanjiangyuan National Park, China. Ecol. Evol. 9, 6643–6654. https://doi.org/10.1002/ece3.5243.

Zhang, J., Yin, N., Li, Y., Yu, J., Zhao, W., Liu, Y., Fu, B., Wang, S., 2020. Socioeconomic impacts of a protected area in China: an assessment from rural communities of Qianjiangyuan National Park Pilot. Land Use Pol. 99, 104849 https://doi.org/10.1016/j.landusepol.2020.104849.

Zhang, Y., Xiao, X., Cao, R., Zheng, C., Guo, Y., Gong, W., Wei, Z., 2020. How important is community participation to eco-environmental conservation in protected areas? From the perspective of predicting locals' pro-environmental behaviours. Sci. Total Environ. 739, 139889 https://doi.org/10.1016/j.scitotenv.2020.139889.