Upgrading protected areas can improve or reverse the decline in conservation effectiveness: Evidence from the Tibetan Plateau, China

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Abstract

Protected areas (PAs) are considered essential for maintaining biodiversity. Several governments would like to strengthen the management levels of their PAs (as shorthand for a hierarchy in PA administrative governance) to consolidate their conservation effectiveness. This upgrade (e.g., from provincial- to national-level PAs) means stricter protection and increased funds for PA management. However, confirming whether such an upgrade can produce the expected positive outcomes is key given limited conservation funds. Here, we used the Propensity Score Matching (PSM) method to quantify the impacts of upgrading PAs (i.e., from provincial to national) on vegetation growth on the Tibetan Plateau (TP). We found that the impacts of PA's upgrading can be divided into two impact types: 1) curbed or reversed declines in conservation effectiveness and 2) rapidly increased conservation effectiveness before the upgrade. These results indicate that the PA's upgrading process (including the pre-upgrade operations) can improve PA effectiveness. Nevertheless, the gains did not always occur after the official upgrade. This study demonstrated that in comparison to other PAs, those with more resources or stronger management policies were more effective.

Keywords: Protected areas; Nature reserves; Conservation effectiveness; Conservation management; Tibetan Plateau; Vegetation growth

1. Introduction

Protected areas (PAs) are key for safeguarding biodiversity, preserving ecosystem health, and protecting ecosystem services supply (Watson et al., 2014; Adams et al., 2019; Maxwell et al., 2020). Effective PA management is critical for supporting multiple global strategies, including the Sustainable Development Goals (SDGs), the Convention on Biological Diversity (CBD), and the Paris Agreement (Blicharska et al., 2019; Zeng et al., 2022). There are two ways to improve PA benefits: expanding the area of PAs and/or enhancing their management (e.g., raising the PA management level or increasing management regulations). The debate over the most appropriate of these two approaches has increased recently (e.g., Gray et al., 2016; Adams et al., 2019; Maxwell et al., 2020) because achieving conservation targets involves economic costs that need to be considered.

To jointly halt ongoing biodiversity loss, ecosystem degradation, and the climate crisis, the Post-2020 Global Biodiversity Framework was proposed to protect at least 30% of the planet by 2030 (CBD, 2021). Several conservationists have argued that half the planet needs to be protected by 2050 (Pimm et al., 2018). Additionally, some scholars have shown that expanding PAs can benefit biodiversity, ecosystem services supply and climate change mitigation (e.g., Zeng et al., 2022; Sreekar et al., 2022). However, establishing large PAs restricts economic activities and resource exploitation and may increase land use conflicts. This expansion has important economic costs. For example, it is estimated that to meet the 30% target, which will cost between $103 billion and $177 billion annually, more resources will be needed (Waldron et al., 2020). In addition, expanding PAs with resource shortfalls will decrease the budget per area (Adams et al., 2019; Coad et al., 2019). Without adequate funding to support PA management, conservation targets will be hard to achieve (Wu et al., 2011; Blackman et al., 2015). Therefore, to prevent the abovementioned issues, it is essential to strengthen PA management levels instead of expanding their coverage area (Adams et al., 2019).

Some studies have revealed that where management is better resourced or involves stronger regulations, PA effectiveness is higher (e.g., Bowker et al., 2017; Geldmann et al., 2018; Zhao et al., 2019), while other studies showed the opposite (e.g., Andam et al., 2008). However, these studies usually compared several groups of PAs with different management levels. Such a comparison is challenging because the methods used are often biased due to poor sample comparability across geographic locations, climatic conditions, and socioeconomic contexts (Andam et al., 2008; Gatiso et al., 2022). In addition, current PA effectiveness evaluations are based on comparing a few snapshots in time (e.g., Geldmann et al., 2018; Zhao et al., 2019; Hua et al., 2022b); thus, comparisons need to be extended over time. The assessment of PA effectiveness in two periods can be affected by specific weather conditions (e.g., droughts) or policy events (the launch of forest protection laws), which can lead to an overestimation or underestimation of PA effectiveness. Moreover, the evolution of effectiveness over successive timescales needs to be better quantified. Therefore, a continuous annual PA effectiveness assessment is essential. Additionally, contrasting PA effectiveness before and after a management level change can show the effects of the PA's upgrading on its effectiveness.

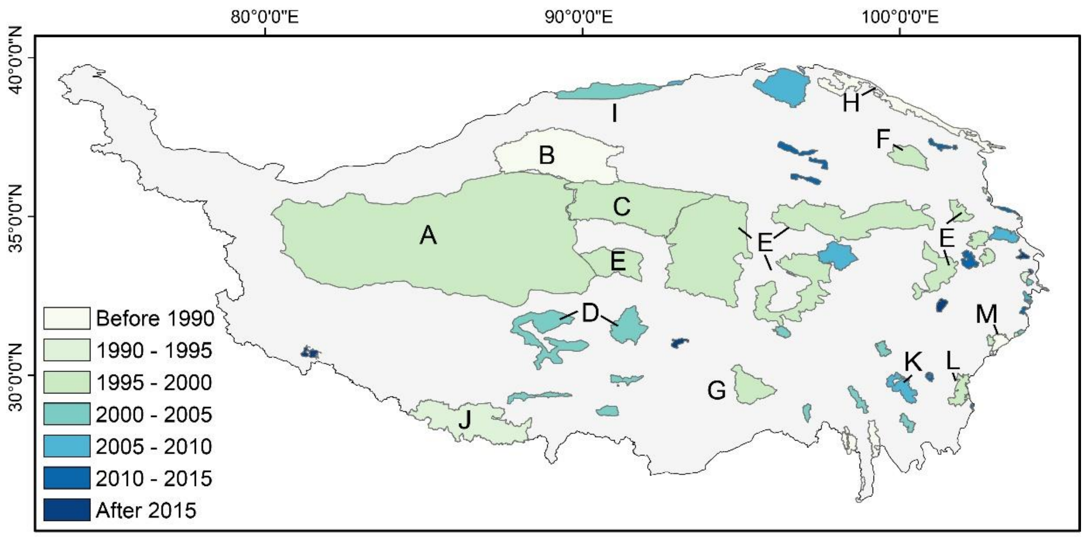
The Tibetan Plateau (TP) is considered a biodiversity hotspot (Myers et al., 2000). One-third of the TP is covered by a dense network of large nature reserves (NRs, the main category of PAs in China). Some studies have shown that establishing these NRs increased vegetation productivity (Zhang et al., 2015) and reduced human activities (Li et al., 2018). Others expressed their concerns regarding the human footprint increase in NRs, which may compromise the benefits of NRs (Li et al., 2018; Hua et al., 2022a). NRs in China can be classified into county, city, province, and national NR levels (The Central Government of China, 2011). Compared to other levels, national NRs are financially supported by the national government and have more funding sources. They also have stricter regulations, such as grazing control and infrastructure construction (The Central Government of China, 2011). The human activities in national NRs' core zones require administrative approval. Additionally, national NRs employ a high number of specialists. More than 70% of the China NRs are located on the TP, which requires a substantial investment in this area. Nevertheless, it is still unknown whether upgrading NR management levels improves conservation effectiveness.

The objective of our work was to determine whether upgrading from the provincial to the national level influences PA effectiveness in terms of promoting vegetation growth on the TP. Thus, we used the Propensity Score Matching (PSM) to quantify the effect of PA's upgrading on the Normalised Difference Vegetation Index (NDVI). The findings will improve our understanding of PA's upgrading role and help optimise management to improve vegetation greenness.

2. Materials and Methods

2.1 Study area

The TP is located in southwestern China and is widely regarded as "the Water Tower of Asia" and "the Third Pole of the Earth" (Yao et al., 2022). It supplies several ecosystem services, such as food and water (Hou et al., 2020; Hua et al., 2021). The TP has harsh climatic conditions and vulnerable ecosystems. Annual precipitation is lower than 1000 mm, and the average elevation is over 4000 m above sea level. Since the 1980s, NRs have been extensively established on the TP (Fig. 1) to protect biodiversity and vulnerable ecosystems. Several policies, such as grazing restrictions or prohibitions, have been applied. Nevertheless, in recent years, in several TP NRs, intensive human activities, such as overgrazing, infrastructure construction, and tourism growth, reduced NRs' conservation effectiveness (Hua et al., 2022a; Jing et al., 2022). Therefore, there are still several concerns regarding PA success on the TP.



A. ChangTang National Natural Reserve
B. Altun National Nature Reserve
C. Hoh Xil National Nature Reserve
D. Selinco National Nature Reserve
E. Sanjiangyuan National Natural Reserve
F. Qinghai Lake National Nature Reserve
G. Yarlung Zangbu Grand Canyon National Nature Reserve
H. Qilian Mountain National Natural Reserve
I. Lop Nur National Natural Reserve
J. Mount Qomolangma National Nature Reserve
K. Haizishan National Natural Reserve
L. Gongga Mountain National Nature Reserve
M. Wolong National Nature Reserve

Figure 1. TP NRs distribution and the date of their upgrading to the national level. Major NR's are labelled as A–M. More details are shown in Tab. S1.

2.2 Data and preprocessing

We used the NDVI data from MOD13A1 with a spatial resolution of 500 m to assess vegetation dynamics (Tab. 1). The NDVI dataset was aggregated into annual values using the Maximum Value Composite (MVC). This method reduced atmospheric noise and cloud cover effects (Huete et al., 2002). If pixels had an annual NDVI value lower than 0.1, then they were treated as non-vegetated and not considered in further analysis. Annual NDVI values from 2001 to 2020 were obtained from Google Earth Engine (GEE, https://earthengine.google.com/). Digital elevation model (DEM), NR boundaries, climate, roads, and settlement data were also collected (Tab. 1). The date when NRs were upgraded from the provincial to the national level was obtained from the People's Republic of

China Ministry of Ecology and Environment.

2.3 Estimation of PA effectiveness on vegetation growth

2.3.1 Propensity Score Matching (PSM) method

In our research, the effectiveness assessment was based on how the presence of PAs increased vegetation greenness. NDVI has been previously used as a proxy for habitat quality (Ma et al., 2022) and is indicative of biodiversity conservation (Pettorelli et al., 2005, 2011) and conservation effectiveness (e.g., Huges et al., 2016; Feng et al., 2021).

To quantify the effect of PAs on vegetation greenness, we compared PA NDVI changes (i.e., treatment group) and unprotected land (control group) from 2001 to 2020. We generated 100,000 random points in the areas where the mean NDVI was greater than 0.1. Approximately 30,000 points were located inside PAs, and approximately 70,000 points were located outside PAs. To prevent spatial autocorrelation, the distance between two sample points was set to at least 1 km (Bowker et al., 2017). The random points located within the 10 km buffer zones of PAs were eliminated as recommended in the literature (Ren et al., 2015; Ford et al., 2020).

Before applying the comparison method to quantify the effects of the PAs on vegetation greenness, the PSM was used to improve the similarity between the treatment and control groups (Schleicher et al., 2019) and reduce the bias (Joppa and Pfaff, 2010). It was assumed that a set of covariates determined vegetation greenness. The matching method was then used to make the covariate values in the treatment and control groups as similar as possible. Therefore, the two groups of random points differed solely in terms of whether they were protected (or not) to eliminate sample selectivity bias and increase the comparability between groups. The NDVI change difference in the treatment and control groups after PSM processing reflected the conservation effectiveness of the PAs.

The core idea of the PSM was to calculate sample propensity scores according to multidimensional variables. Then, the propensity score was used as a distance function (according to the nearest neighbour rules) to match the treatment and control groups. Tab. S2 shows that elevation, slope, annual mean temperature (2000 – 2015), annual mean precipitation (2000 – 2020), distance to settlements, and distance to roads were selected as covariates that potentially affected vegetation greenness based on Ament & Cumming (2016), Ren et al. (2015), and Ford et al. (2020). A stepwise regression was applied to identify the variables with the highest explanatory power. Thus, elevation, annual mean precipitation, and distance to settlements were identified as the final covariates to use in the PSM with an adjusted R^2 of 0.635. The NDVI values for 2001 were also included as one of the covariates since we wanted to approximate the initial vegetation status in the treatment and control. Stepwise regression was carried out with the Statistical Package for Social Science (SPSS 22), and the PSM method was carried out using the R package 'MatchIt' (Ho et al., 2018). We set a standard deviation calliper of 0.25 for each covariate during the matching process and used a t test (significant differences were considered at $p < 0.05$) for covariates before matching to improve the matched point pairs' quality. The number of matched points in each NR and PSM balance test result are shown in Tab. S3.

2.3.2 Effectiveness estimation

The ratio of the cumulative value of the annual NDVI of the treatment groups to that of the control groups outside the NRs was used as the effectiveness metric (E_{yr} in formula (1)). To quantify the effectiveness, after PSM processing, we annually counted the NDVI value within the treatments ($\sum_{2001}^{yr} VI_{NR}^{yr}$) and their corresponding controls ($\sum_{2001}^{yr} VI_{non-NR}^{yr}$). The NDVI value of each year was considered the NR effectiveness calculation, which addressed the problem of considering only a few time nodes of NDVI when calculating effectiveness. Furthermore, the ratio of the two was multiplied by the correction coefficient α to obtain the metric effectiveness.

$$E_{yr} = \alpha * \frac{\sum_{2001}^{yr} VI_{NR}^{yr}}{\sum_{2001}^{yr} VI_{non-NR}^{yr}} \quad (1)$$

where VI_{NR}^{yr} refers to the average NDVI within the treatments for a given year *yr*. $\sum_{2001}^{yr} VI_{NR}^{yr}$ refers to the NDVI sum within the treatments from 2001 to a given year *yr*. VI_{non-NR}^{yr} refers to the average NDVI within the matching controls for a given year *yr*. $\sum_{2001}^{yr} VI_{non-NR}^{yr}$ refers to the sum of the average NDVI within the matching controls from 2001 to a given year *yr*. E_{yr} refers to the NR effectiveness and reflects the NR cumulative effect on improving NDVI from 2001 to *yr*. α is the correction coefficient. The introduction of α can correct the E_{yr} initial state to 1. If E_{yr} is greater than 1, then it indicates a positive effect and vice versa. If E_{yr} is 1 + *x*%, then the PA cumulative effect on vegetation growth from 2001 to *yr* is *x*%. Formula (1) was used to calculate the effectiveness of each NR. The formula's input is the yearly NDVI value of the NR treatment group and its matched control group after PSM analysis. We assessed the NR conservation effectiveness trend and cumulative effect with this formula.

The correction coefficient α was the NDVI cumulative sum reciprocal observed in the first three years (treatments and controls) (formula (2)).

$$\alpha = \frac{\sum_{2001}^{2003} VI_{non-NR}}{\sum_{2001}^{2003} VI_{NR}} \quad (2)$$

The correction coefficient α was based on the relationship between the NDVI of the treatment and control groups in the previous three years (i.e., 2001 – 2003), correcting the value calculated for 2003 in formula (1) to 1. Therefore, the effectiveness calculation started in 2003 with an initial E_{yr} of 1, and the calculated effectiveness (E_{yr}) for the subsequent years was compared with 1. In addition, we considered two other correction coefficients (see Supplementary Material for details).

After calculating each NR's effectiveness, the total NR's effectiveness was evaluated using formula (3). This formula considered the proportion of one NR's NDVI to all NRs' NDVI as a weight.

$$E_{yr}^{total} = \sum_{i=1}^{51}\left(\frac{NDVI_{NR_i}}{\sum_{i=1}^{51} NDVI_{NR_i}} \times E_{yr}^{NR_i}\right) \quad (3)$$

where E_{yr}^{total} is the total effectiveness of all NRs on the TP for a given year yr. $E_{yr}^{NR_i}$ is the effectiveness of a given NR (NR_i) in a given year (yr). Its calculation was based on formula (1). In our research, we considered 51 NRs. $NDVI_{NR_i}$ is the sum of NDVI within a given NR (NR_i), and $\sum_{i=1}^{51} NDVI_{NR_i}$ is the sum of NDVI within all NRs. We considered the NDVI sum for each NR from 2001 to 2003, consistent with the correction coefficient α obtained in formula (2). Similarly, if E_{yr}^{total} is greater than 1, it shows a positive effect of all NRs on the TP and vice versa. If E_{yr}^{total} is 1+$x\%$, all PAs' cumulative effect on vegetation increased from 2001 to yr is $x\%$.

2.3.3 NRs upgrading effect

Our analysis was mainly focused on the NR's upgrading effect from the provincial to the national level. A linear fitting was conducted for the NRs at the provincial (2003 to the year updated to the national level) and national level stages (the year updated to the national level to 2020).

Conservation effectiveness (E_{yr}) was used as the dependent variable, and the corresponding year of conservation effectiveness was the independent variable. The NRs' upgrading effect was then demonstrated by comparing the sign and slope of the two fitting lines before and after the upgrading year. Due to the availability of vegetation data and the linear fitting data input requirement, we only considered NRs upgraded to a national level between 2005 and 2015.

3. Results and discussion

3.1 NR effectiveness and evolution

The results showed that NRs had a total weak effectiveness (E_{yr}^{total}: 1.0057) in the past two decades. This result indicated that PA establishment could increase the NDVI by 0.57% (Fig. 2a). Additionally, the total effectiveness of the PAs showed a decreasing fluctuating trend. We identified a peak in 2005 (E_{yr}^{total}: 1.0087) and a decline from 2005 to 2009 and 2012 to 2017, respectively (Fig. 2a).

Thirty-one NRs had positive cumulative effects from 2001 to 2020, accounting for 44.9% of the PAs. Most were located in the centre and east of the study area. The reduced total effectiveness was mainly because Changtang NR, the largest of the TP's NRs, had a very weak negative cumulative effect (E_{yr}: 0.992). From 2005 to 2012, the conservation effectiveness of Sanjiangyuan NR and Hoh Xil NR increased substantially. The cumulative effect of several small-size NRs (e.g., Yading and Haizishan NRs) located southeast of the TP shifted from negative to positive (Fig. 2b, d). Fig. 2f shows that the change in effectiveness transformation occurred in two phases (from 2005 to 2009 and from 2012 to 2017). The first phase mainly transformed between two conservation effectiveness types with E_{yr} values of "1–1.01" and "1.01–1.03". The second phase mainly transformed between two conservation effectiveness types with E_{yr} values of "1–1.01" and "0.99–1", accounting for 81.2%.

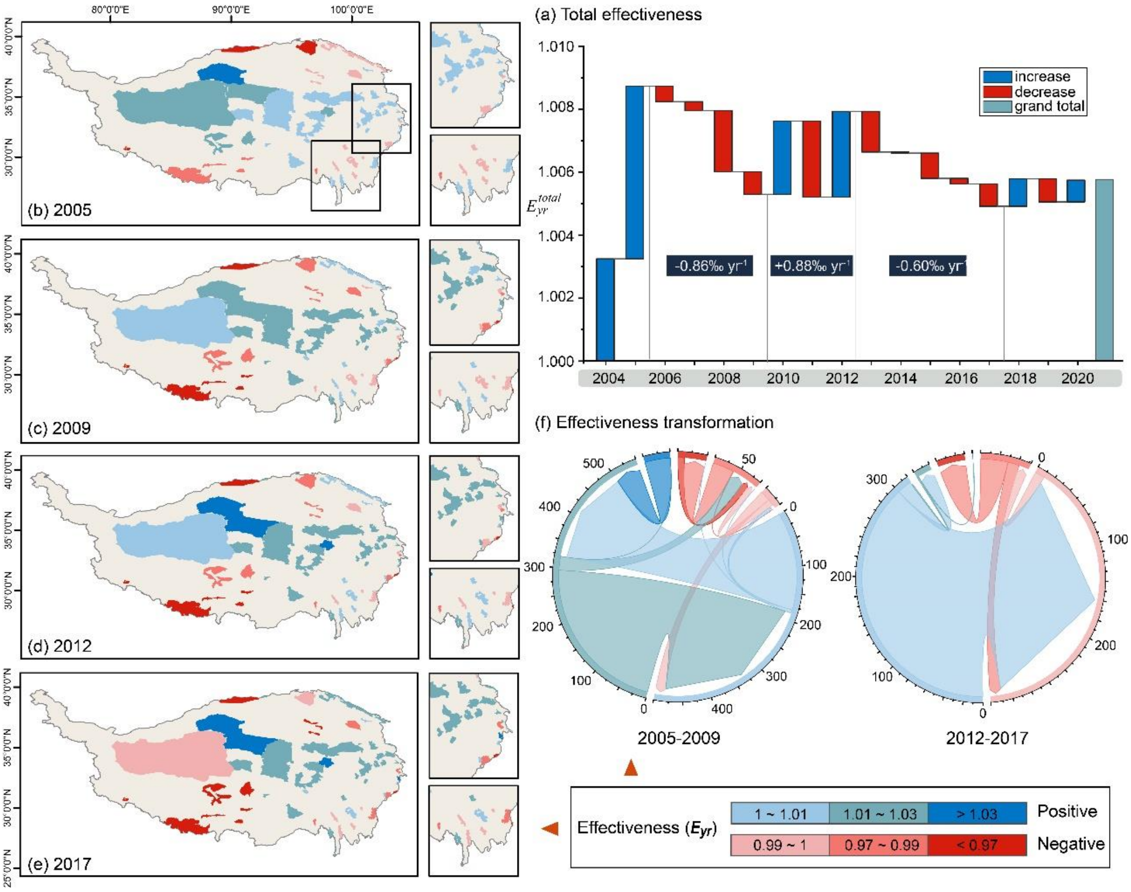


Figure 2. Evolution of NRs' effectiveness in TP. (a) is the NRs total effectiveness trend in TP. The calculation of total effectiveness was based on formula (3). b–e) is the effectiveness of each NR on NDVI in different time nodes. The calculations were based on formula (1). The choice of time nodes in panels (b–e) was based on the stage division of the effectiveness' evolution in a). f) shows the shifts between different effectiveness types from 2005 to 2009 (left) and from 2012 to 2017 (right). The direction pointed by the arrow's end and the arrow's colour is the effectiveness types for the first-time node. The arrow's direction and corresponding colour are the effectiveness types for the second time node. The arrow's width indicates the area of the effectiveness shifts, and the number

around the circle indicates the area (unit: 10^4 km^2). Six effectiveness types were considered in the legend, and different colours represent different effectiveness, which was calculated according to E_{yr} in formula (1).

Comparing our results to those obtained in other countries, such as South Africa (Ament and Cunmming, 2016) and Brazil (Gonçalves-Souza et al., 2021), the relative contribution of NRs to TP was relatively low (0.57%). Similar findings were identified by Zhao et al. (2019) in Southwest China, where a small relative contribution (1%) was identified. This could be attributed to the implementation of large-scale ecological restoration programs on the TP, which improved the vegetation growth baseline (control group). These restoration programs reduced the differences between the treatment group (inside PAs) and the control group (outside PAs). Since the late 1990s, the Chinese government has launched several large ecological restoration programs on the TP, such as the Grain for Green Program and the Natural Forest Protection Program (Bryan et al., 2018). Since then, a greening trend has been detected (Cai et al., 2015; Xu et al., 2016; Ning et al., 2022). This partly concealed the effectiveness of the PAs. In particular, since the launch of the first and second phases of the Sanjiangyuan ecological protection and construction programs in 2005 and 2014, respectively, PA effectiveness has continuously declined. However, it was still positive (Fig. 2a).

3.2 Upgrading effect of PAs on vegetation growth

Eleven NRs were upgraded to a national level between 2005 and 2015 on the TP. Among the 11 NRs, 3 NRs showed a decreasing trend in conservation effectiveness before upgrading to the national level. However, after upgrading, they showed an increasing trend in conservation effectiveness (Fig. 3 b, g, k). Additionally, the negative Liziping NR conservation effectiveness trend was reduced after the upgrading (Fig. 3d). In the other 5 NRs (Fig. 3. a, c, h, i, j), conservation effectiveness increased rapidly several years before the upgrade and subsequently slowed. In contrast to the abovementioned results, the conservation effectiveness of the Qaidam *Haloxyon ammodendron* forest NR (Fig. 3e) and Xiaozhaizigou NR (Fig. 3f) declined rapidly after the upgrade. Overall, the effects of upgrading on PAs fell into two categories: 1) curbed or reversed decline in conservation effectiveness and 2) the conservation effectiveness increased rapidly before the upgrade, slowing down subsequently.

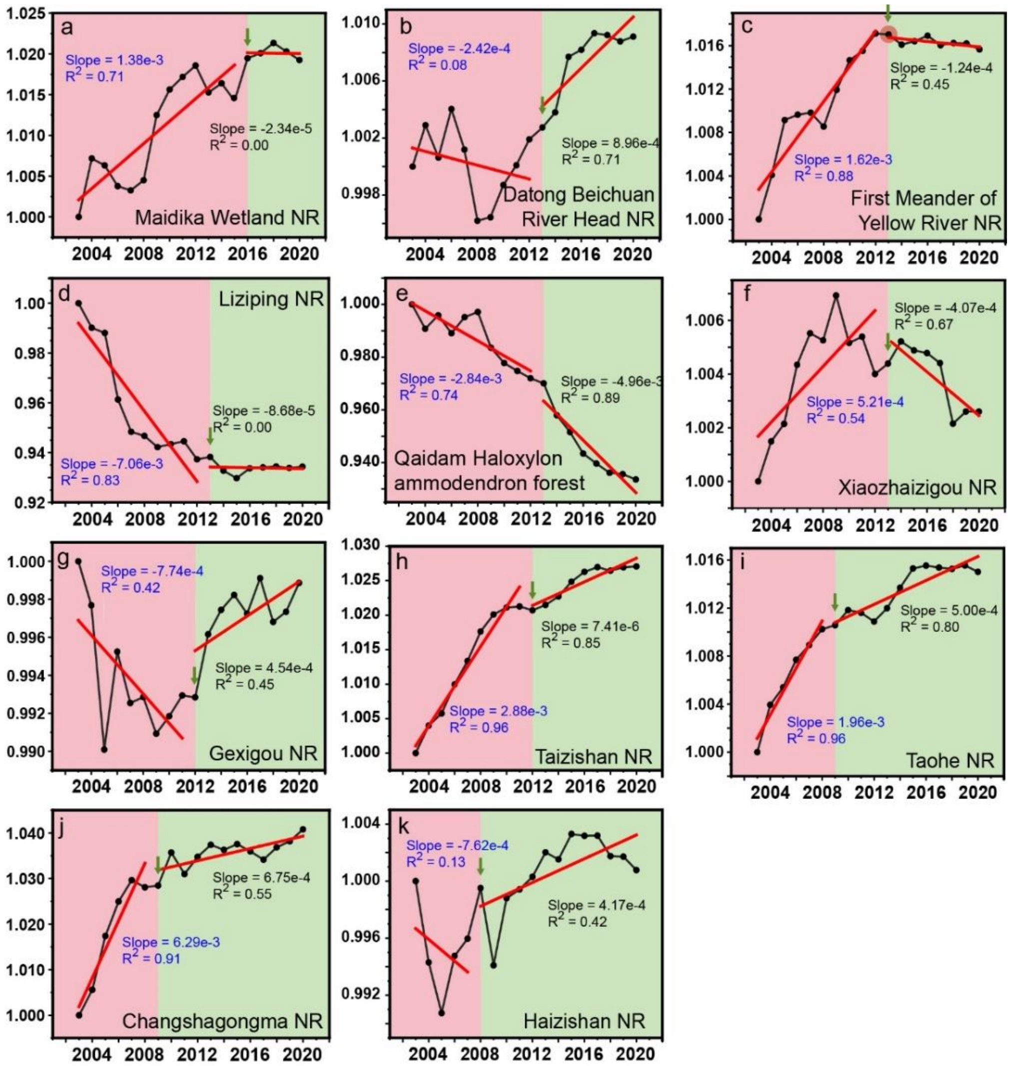


Figure 3. Upgrading effect of PAs on vegetation greenness. The Y-axis shows the effectiveness according to E_{yr} calculated. The pink part (left) is the phase of NR at the provincial level, and the green colour (right) is the phase of NR at the national level. The year corresponding to the intersection of pink and green colour is the year of each NR upgrade. The red line is the fitting line, and the blue (black) characters mark the slope and R^2 of the fitting line at the provincial (national) level.

In China, PA's upgrading requires the approval of higher authorities. Local governments perceive the PA's upgrading as an administrative achievement and a potential source of tourism income (Jim & Xu, 2004). Therefore, to successfully pass the scrutiny of the upgrading process, local NRs increase investment and renovation efforts. It signifies that a few years before the official upgrade to the national level, the local government has already increased its efforts and funding for protecting and managing NRs. As a result, the effectiveness of upgrading NRs occurs before the official upgrade. This partly explains the increased conservation effectiveness before the official upgrade (e.g., Fig. 3. a, c, h, i, j).

After the upgrading, the flat conservation effectiveness trend may be related to national NRs embracing more advanced management concepts, such as ecosystem authenticity (Xia et al., 2021). Management favours passive restoration (Crouzeilles et al., 2017) and natural ecosystem recuperation without human impacts. Overall, considering the whole process of PA's upgrading (including the pre-upgrade operations), 9 out of 11 cases on the TP showed that upgrading PA's management level improved their effectiveness by promoting vegetation growth. Nevertheless, the gains did not always occur after the official upgrade.

3.3 Potential causes of PA effectiveness

Infrastructure construction and overgrazing are the main drivers of decreased PA vegetation growth. Expanding road and railway construction across PAs has increased vegetation loss and habitat fragmentation (Huang et al., 2019; Hua et al., 2022a), hampering conservation effectiveness. Grazing is the primary source of income on the TP (Li et al., 2013; Fan et al., 2015). Long-term overgrazing or poor grazing management has resulted in alpine grassland degradation (Cai et al., 2015). For example, the residents in Selinco NR live in extreme poverty, which pressures them to expand grazing activities (Yang & Yang, 2021). Long-term overgrazing increases grassland degradation, negatively affecting the conservation effectiveness of PAs (Fig. 2b). For instance, Mount Qomolangma NR did not implement grazing prohibitions and relied on the grass-livestock balance incentive policy (Gan, 2019). However, the livestock pressure in the region has been high, partly explaining this reserve's poor performance. In the Sanjiangyuan NR, some ecological restoration and eco-compensation programs (e.g., “Retire livestock and restore grassland” in 2003) were launched to reduce the grazing impact on NRs (Wang et al., 2018). Therefore, as expected, there has been an increase in conservation effectiveness in the Sanjiangyuan NR and its surrounding NRs (Fig. 2b, c, d). In addition, the impact of climate change must be considered. From 1970 to 2010, the climate in northwestern Tibet had a warming and drying trend, reducing grass growth. This partly explains the negative conservation effectiveness observed in the Changtang NR (Fig. 2e), as Zhang et al. (2015) identified.

3.4 Upgrading management level vs. expanding PAs.

Two typical approaches were used to improve PA outcomes: upgrading the management level and expanding PA’s coverage. Expanding PA coverage is useful for improving the representativeness of conservation objectives (Fig. 4). Some scholars have expressed concerns about the low representation of PAs on the TP. They highlighted the importance of protecting the southeastern part of the plateau because of its high biodiversity and ecosystem services supply (e.g., Li et al., 2020). The low PA representativeness on the TP is mainly due to the lack of a clear conservation strategy and information (e.g., biodiversity and ecosystem services maps) when PAs are designed (Wu et al., 2011; Wu et al., 2018). Expanding PAs often requires large investments, such as direct management costs (e.g., daily operation, infrastructure, and equipment costs) and opportunity costs from alternative land use (Chen, 2020). It was estimated that PA opportunity costs account for 98.3% of total costs in China (Yang & Wu, 2019). Local government and people support these costs and a potential loss of revenue. Consequently, PA expansion is often perceived as a barrier to economic development and a constraint on local people's livelihoods (Chen et al., 2017). Therefore, assessing the trade-offs associated with PA expansion (e.g., Gray et al., 2016; Adams et al., 2019; Chen, 2021) is paramount.

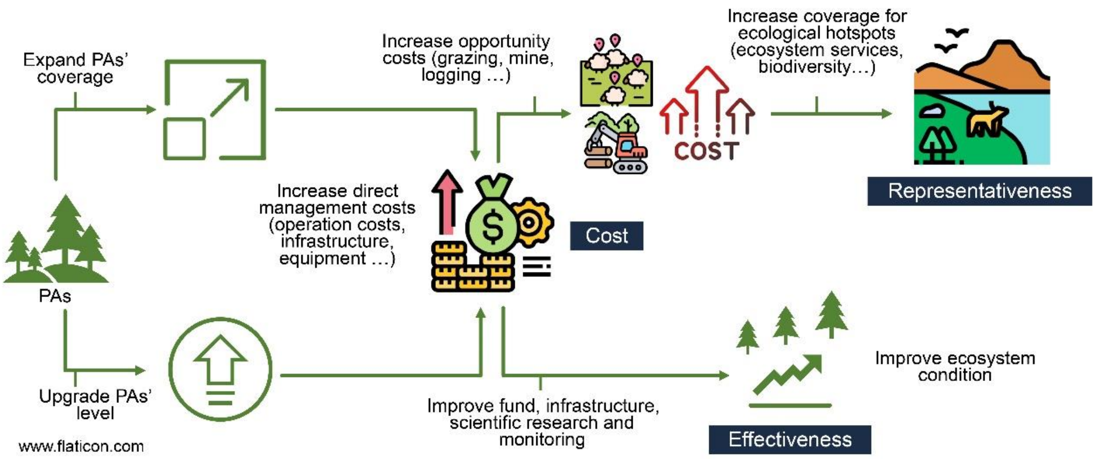


Figure 4. Tradeoffs between cost, representativeness, and effectiveness of the two approaches (upgrading management level VS expanding PAs).

Our analysis revealed that upgrading PAs management levels can improve their conservation effectiveness (Fig. 3). In comparison to provincial NRs, national NRs are generally better funded, have stricter monitoring and protection, and receive more scientific attention (Zhang et al., 2017; Feng et al., 2021). Adequate financial investment and scientific research can strengthen ecosystem monitoring, which can support and guide PAs to adopt more appropriate measures to improve their effectiveness (Hu et al., 2019). Nevertheless, as highlighted by previous scholars (e.g., Li et al., 2020; Hua et al., 2022c), more than upgrading PAs, it is necessary to narrow the TP conservation gaps.

3.5 Policy implications for PA management

Our results demonstrated that PAs could play a key role in the greening observed on the TP, indicating that restoration and conservation programs have contributed to vegetation improvement in this region. However, several small-size NRs located in the southeast, Mount Qomolangma NR and Selincuo NR, exhibited negative conservation effectiveness (Fig. 2). This is primarily related to the deforestation or overgrazing conducted by residents around the reserves. Several PAs have large areas collectively owned by local residents that have used their lands in the same way for decades (Zhang et al., 2017). Conservation objectives and local community practices trigger conflict between the PA residents and management authorities. Furthermore, PA management should consider the effect of PAs on the wellbeing of PA neighbourhoods (Cumming & Allen, 2017). Some solutions, such as payment for ecosystem services, land leasing and ecological migration, can be established to achieve the targets of nature conservation and poverty alleviation.

Since economic activity is reduced on the TP, local governments need more revenue, and the capacity for investment in conservation is reduced. The central government generally supports national NRs financially, making them more sustainable. Therefore, TP local governments should actively establish national NRs if the conditions permit. This can alleviate the local government's financial burden for conservation and improve the expected conservation benefits. Furthermore, consistent and adequate funding can strengthen monitoring and research and increase staff. These aspects are vital to improving PA effectiveness.

3.6 Limitations and future perspectives

Some limitations and uncertainties should be considered in further studies. First, a vegetation index (NDVI) was used to measure PA effectiveness. It is a common practice (e.g., Huges et al., 2016; Feng et al., 2021; Hua et al., 2022b) and has the advantage of time series availability. Additionally, it indirectly reflects conservation effectiveness through habitat quality improvement (Ma et al., 2022). Future research should consider more comprehensive metrics to depict conservation effectiveness, such as human activities or invasive species. The matching methodology has been widely used for the assessments of PA effectiveness, but it has some limitations. For instance, matching effects depend on including the main determinants of vegetation growth, which are only sometimes known. The lack of covariates may also limit the accuracy of effectiveness quantification. Another concern is the different data resolutions (e.g., DEM data) and temporal scales (e.g., annual mean temperature and precipitation), which can result in some errors in the modelling process. These limitations were also highlighted in previous works (e.g., Gomes et al., 2021). In addition to the method applied in this paper, the PAs' upgrading effect can also be quantified by comparing the performance between provincial-level (i.e., control group) and national-level NRs (i.e., treatment group) with similar social and natural backgrounds. However, the results also depend on the study area and data availability. Given the availability of vegetation data to apply this method, we considered NRs upgraded to a national level between 2005 and 2015 (see Section 2.3.3 for details). Several TP NRs were upgraded to the national level before 2000.

Thus, only a small number of NRs were used as a control group, posing a challenge to meet the 'matching' method requirement. Additionally, the contribution of conservation programs (i.e., PAs) and restoration programs (e.g., ecological engineering) to vegetation growth should be analysed individually. This would be key to understanding their impacts on conservation effectiveness and providing information for future PA management plans.

4. Conclusion

Before PA expansion, a thorough analysis must be conducted because of the limited conservation budgets and substantial opportunity costs involved. Taking the TP's PAs as examples, this study examined the effect of upgrading PAs' level on conservation effectiveness, one of the most direct ways to enhance PA management. The process of PA's upgrading, including the pre-upgrade operations, effectively improved their conservation effectiveness. Nevertheless, the gains did not always occur after the official upgrade. This highlights that upgrading PA's level is essential for maximising their potential to reduce biodiversity and vegetation loss. However, although aware that upgrading PAs can address issues related to conservation effectiveness, there is a need to address the representativeness problem. There are important conservation gaps in the southeastern part of the TP, which has high ecosystem services and biodiversity values. Research on PA's upgrading effects can enhance our understanding of PA conservation effectiveness, which is essential for identifying the potential benefits of improving management. This information can also serve as the basis for decision-making and conservation optimisation.

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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.

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