# Socio-economic development shows positive links to the conservation efficiency of China's Protected Area network

**Running Title:** Protected Areas conservation efficiency

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**Abstract**

While the protected area covers >15% of the planet's terrestrial land area and continues to expand, factors determining its effectiveness in conserving endangered species are being debated. We investigated the links between direct anthropogenic pressures, socioeconomic settings and the coverage of vertebrate taxa by China's protected area network, and indicated that high socioeconomic status and low levels of human pressure correlate with high species coverage, with Threatened mammals more effectively conserved than reptiles or amphibians. Positive links between conservation outcomes and socioeconomic progress appear linked to local livelihood improvements triggering positive perceptions of local protected areas– aided further by ecological compensation and tourism schemes introduced in wealthy areas and reinforced by continued positive conservation outcomes. Socioeconomic development of China's less developed regions might assist regional protected area efficiency and achievement of the Kunming-Montreal Global Biodiversity Framework, while also addressing potential shortcomings from an insufficient past focus on socioeconomic impacts for biodiversity conservation.

**Key words: Biodiversity, 'ecological civilization', human activities, nature reserve, sustainable development**

## 1. Introduction

Protected Areas (PAs) are crucial elements of global biodiversity conservation that protect important habitats and species (Timmers et al., 2022; Visconti et al., 2019). Covering ~15.9% of the earth's land area, the PA has increased rapidly in response to Aichi Target 11 benchmarks (Geldmann et al., 2019). This growth focus has arguably partly superseded the focus on targeted designation of areas of particular importance for biodiversity and threatened species. Simultaneously, the conservation effectiveness of PAs has been increasingly questioned (Jonas Geldmann et al., 2015; Maxwell et al., 2020; Watson et al., 2014), with regards to PA management (Kearney et al., 2018), and the conservation efficiency for habitats and species (Schulze et al., 2018). For example, iconic conservation flagship species like rhinoceros or large carnivores experience population declines even in strictly protected nature reserves (IUCN Category Ia) (Craigie et al., 2010). Furthermore, famous PAs are often still reporting significant ecological degradation (Rija et al., 2013). PA performance, referring to the actual results of conservation efforts within protected areas, such as the number of species sustained or the increase in population sizes of threatened species, may be impeded by insufficient financial and staff resources (Lindsey et al., 2017), ineffective law enforcement and weak resource management (Chowdhury et al., 2022). Conflicts also arise from protected species venturing from PAs into adjacent agricultural areas or settlements, potentially causing significant economic damage and resulting in local opposition to the PAs' existence (Holmes, 2007; Clark et al., 2013).

Conservation efficiency, referring to the balance between the resources put into a conservation program or PA and the resulting conservation achievements or outcomes, depends on numerous factors beyond direct human interferences (Cumming & Allen, 2017; Palomo et al., 2014). These include regional economic priorities, education standards and PA governance. Accordingly, large-scale regional socioeconomic development has been reported to benefit PA conservation efficiency (Oldekop et al., 2016; Palfrey et al., 2021), implying that countries with a high GDP or rapid economic growth are associated with superior conservation outcomes for rare and threatened species within their PAs networks.

China's PA network is central to national biodiversity and habitat conservation strategies (Sun et al., 2020), with national nature reserves being particularly important. Responding to past environmental degradation, China has aimed at biodiversity conservation through a rapid expansion of its PA (Figure 2a) that covers >18% of its total land area, with numerous relatively small PAs largely responsible for post-2008 increases in total PA numbers. Recently, a number of lower-level PAs were downsized or even degazetted, resulting in a slight recent decline in the total protected area (Li & Pimm, 2020), while China's economic growth model is transitioning from 'high-speed' to more targeted 'high-quality' growth since 2010 (Figure 2b) (Bryan et al., 2018). This setting, and the still vastly different state of local economies across China's provinces, allow for a great case study to explore potential links between socio-economic settings and conservation outcomes.

China's PA expansions coincided with population increases for a number of endangered taxa, including the giant panda (*Ailuropoda melanoleuca*), Siberian tiger (*Panthera tigris altaica*), and the formerly nationally extinct Amur leopard (*Panthera pardus orientalis*) (Council, 2016). Moving forward, it is critical to assess the species conservation effectiveness of China's PA network beyond key iconic species in light of the country's ongoing, rapid transformations in economic status, rapid urbanization and associated changing pressures on the natural environment, as the country also aims to transform towards a more sustainable 'ecological civilization' (Lu et al., 2019). The 'ecological civilization' concept refers to sustainable development approaches that balance economic expansion with environmental and natural resource protection, biodiversity conservation, climate change mitigation and a general reduction of pollution levels. A plethora of studies has focused on species conservation efficiency and protected area performance at small spatial scales, looking for example at individual threatened species in area-based population viability analyses (PVA) and at PA habitat quality and suitability for target species (Larson et al., 2004). Accordingly, recording species population dynamics in PAs is commonly used to assess PA conservation performance (Cazalis et al., 2020). Species distribution patterns and species richness within PAs have been studied at larger spatial scales, too (Chape et al., 2005; Guo et al., 2019). Here, low human disturbance levels in PAs generate positive conservation outcomes (Jones et al., 2018).

While relationships between species conservation outcomes within PAs and direct drivers like direct human interferences and climate-related factors have enjoyed substantial attention, impacts of more drivers acting more indirectly, like socio-economic factors remain less well understood. To fill this gap, we now link the distribution of China's threatened vertebrate taxa to the country's rapid, spatially highly uneven economic development– as a case study to test the hypotheses that 1) China's existing PA network effectively protects the distribution ranges of species categorized as Threatened according to IUCN Red Lists, 2) the conservation effectiveness of PAs for Threatened species is lower in areas experiencing a high human impact, characterized by 13 anthropogenic stressors (Theobald et al., 2020), and 3) the conservation effectiveness of PAs is positively linked to regional economic prosperity.

## 2. Materials and Methods

Based on these hypotheses, we modified the work of Geist & Lambin (2002) to create a conceptual framework that ties socioeconomic variables and 'human effects'- factors to the rise and decline of nature reserve conservation effectiveness, respectively (Figure 1). Socioeconomic factors we considered are combined the Human Development Index (HDI, Schmidt-Traub et al., 2017), including GDP, educational standards, and life expectancy. The potential causes for the assumed positive conservation outcomes related to the HDI include economic incentives, poverty reduction, alternative livelihoods, ecotourism development, increased environmental education and awareness, and the conservation of indigenous knowledge. Collectively, they represent socio-economic empowerment of individuals and communities through socio-economic factors to achieve positive conservation outcomes, emphasizing not only the importance of the general socioeconomic context in conservation efforts, but demonstrating the potential for direct, coordinated conservation efforts with increasing investment in positive outputs.

Declines in biodiversity within nature reserves in turn are assumed to result from decreasing conservation efficacy as a result of direct anthropogenic interference. The 'Global Human Modifications' (GHM) dataset was utilized to depict specific elements such as built-up areas, agricultural, transportation and service corridors, infrastructure related to energy production and mining, biological harvesting, pollution and human intrusions. Within nature reserves, additional, proximate causes include habitat fragmentation, resource overexploitation and illegal trade, ecosystem alteration, and other human-induced degradation. We appreciate that variables such as climate change and urbanization substantially influence the state of nature reserves, too, but these were outside the scope of our research.

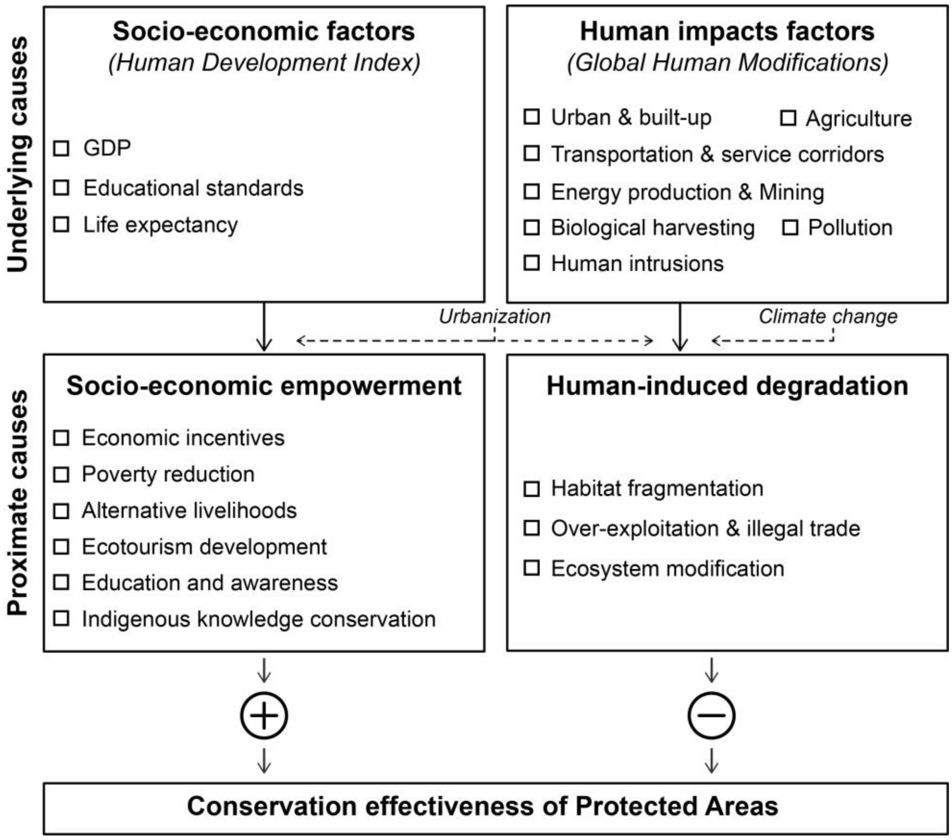


**Figure 1** Conceptual framework linking socioeconomic factors and human impact to the conservation effectiveness of protected areas (modified from Geist & Lambin (2002))

## 2.1 **Study area**

We focused our investigations on the 788 nature reserves where concrete spatial information regarding their spatial context were readily available from WDPA datasets, government agencies and institutions, or nature reserve websites. They represented 322 national-, 235 provincial- and 231 county-level reserves (Figure 2c; Figure S1). Of these, national nature reserves receive most funding. They also have permanent staff and an independent administration. While in combination, the selected reserves only represent 28% of China's total PA number, their combined area accounts for~70% of China’s PA (Figure S1). The remaining nature reserves lack clear boundaries and/or extensive associated documentation, making them ineligible for consideration in this paper. About half of the nature reserves (n=389) we selected overlapped with China's critical biodiversity areas and key national ecoregions. For more than two thirds (n=263) of these, the overlap exceeded 80% (Figure S2 in the Supporting Information). Given the areal coverage of the selected nature reserves and the good representation of China's important ecoregions, we believe that they form a representative sample for all PAs in China.

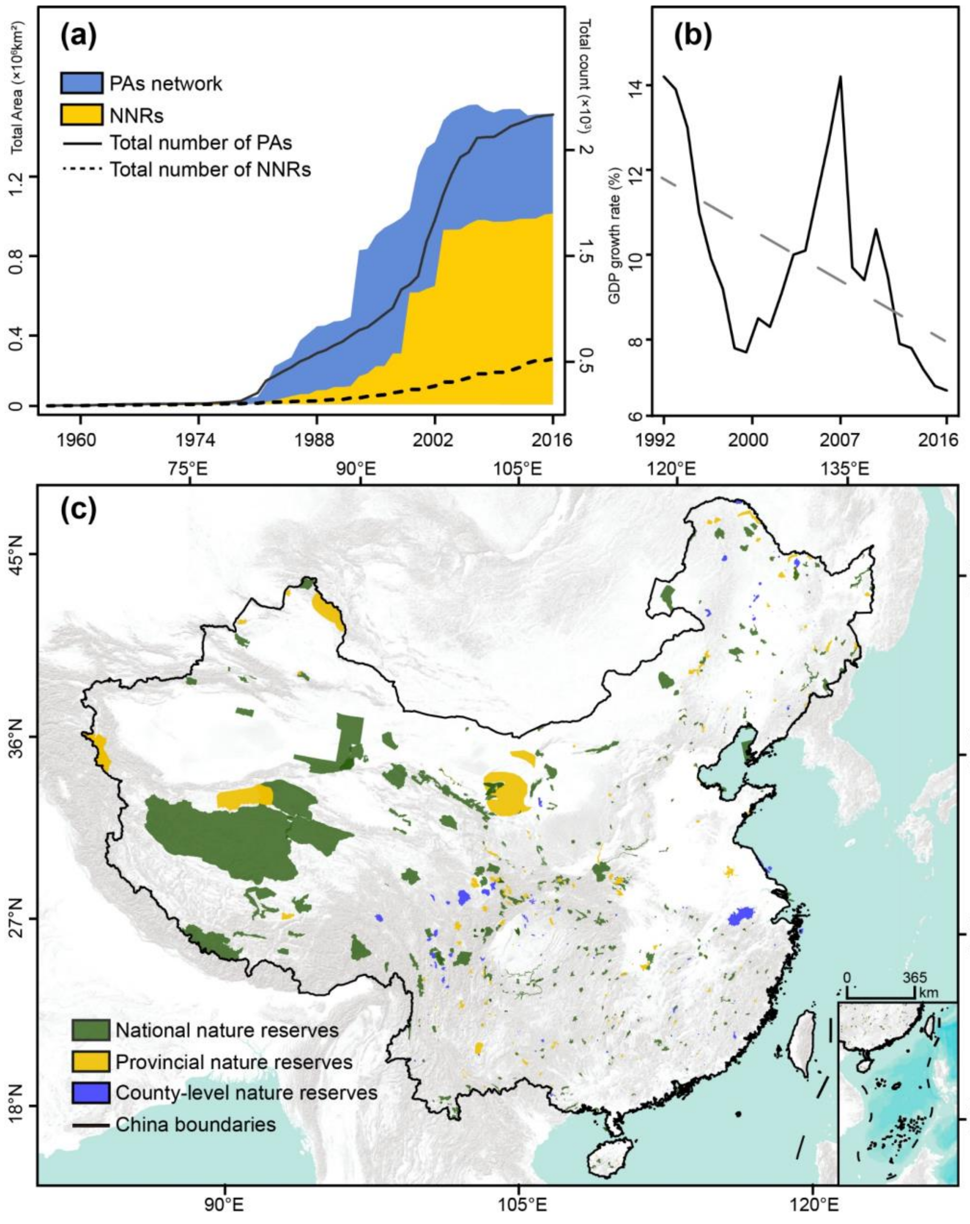


**Figure 2** China's Protected Area and national nature reserve coverage and number (a), China's GDP growth rate (b) and distribution of the 788 considered nature reserves on a 1:1,000,000-scale (c). Statistical data in (a) and (b) were obtained from Wang et al (2010) and the National Bureau of Statistics, respectively. Note: map lines delineate study areas and do not necessarily depict accepted national boundaries

### 2.2 IUCN Red List species and distribution ranges

Extent of Occurrence (EOO) and Area of Occupancy (AOO) are two vital parameters in the IUCN red list. Here, we chiefly focused on the EOO of the respective species reviewed in the IUCN red list, which is advantageous for scientific research due to its comprehensive coverage of numerous species, standardized criteria and categories for assessments that ensure consistency and transparency, detailed information on species' characteristics and conservation needs, as well as regular updates based on new data and expert input (IUCN, 2022), while we present the estimated AOO of all Critically Endangered species in the Supporting Information. EOO is the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon (Brooks et al., 2019). To evaluate the EOO of the species evaluated in the IUCN red list, we established the overlap between China's PA network and the distribution of its red-listed species, and we employed the 'Spatial Data Download' option (https://www.iucnredlist.org/resources/spatial-data-download) to obtain shape files and point data representing the distribution of the respective species. Given data access and data quality concerns, we concentrated our research on mammals, amphibians, and reptiles. The scarcity of IUCN red list assessments for terrestrial invertebrates unfortunately disallowed their inclusion in our study – while acknowledging that the huge prevailing data gaps for mega-diverse invertebrate taxa require urgent attention to inform effective holistic conservation strategies (Zhu et al., 2021).

### 2.3 Species conservation effectiveness

We defined ‘conservation effectiveness’ of national nature reserves, provincial nature reserves and county-level nature reserves by evaluating how many distribution ranges of endangered species of mammals, amphibians and reptiles were covered by PAs. On the one hand, such measures of species richness represent a highly informative conservation goal easily understood by the general public and policy stakeholders. This measure is also intricately connected to a wide range of environmental factors, including climate change, alien species invasions, pollution, land-use changes and associated habitat degradation and loss, and the over-exploitation of natural resources, with the latter direct drivers often linked to socioeconomic factors such as poverty and a lack of education. On the other hand, this measure is fundamental for the evaluation of ‘conservation efficacy’, which in our study refers to the degree to which conservation efforts have been successful in increasing the number of species in one/one type of specific nature reserve. This in turn allowed us to link socioeconomic and other factors to the conservation status of nature reserves.

We further differentiated distribution ranges of the three taxonomic groups by IUCN Red List categories of Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC) (additional details of IUCN Red List are given in Supporting Information 2.1), determining the proportions of respective species covered by overlaying the PA map with individual species’ distribution maps. Species classified as either Critically Endangered,

Endangered, or Vulnerable will in the following be referred to as Threatened. We subsequently also mapped the nature reserves' species richness for Threatened, Near Threatened (NT), and Least Concern (LC) -species. Finally, we assessed the species cover across the entire PA network across all threat categories.

**2.4 Evaluation of human impact and socioeconomic status**

We specifically analyzed conservation efficiency of the PA network in view of socio-economic and other anthropogenic factors. We employed two measures - one characterizing human impact intensity and one describing the socioeconomic status (Additional details are given in Supporting Information 2.4). Human impacts were quantified using the Global Human Modification (GHM) approach that combines the 13 anthropogenic stressors human population density, % of built-up area and cropland, livestock numbers, major and minor roads, two-track roads, rail lines, mines, oil wells, wind parks, power lines, number of night-time lights and their approximate combined intensity (Theobald et al., 2020). The GHM dataset at a 1 $km^2$ resolution following Kennedy et al. (2019), is a metric that varies between 0 (no pressure) and 1 (extreme pressure) to characterize the combined degree to which the environment has been modified and experiences human modification pressures (Riggio et al., 2020). We used an average GHM value across each PA to reflect human impact, utilizing zonal statistics on each of the explicit nature reserves boundaries. To characterize and quantify the socioeconomic status, we used the Human Development Index (HDI) that measures regional development across three dimensions: GDP, educational standards, and life expectancy. Official HDI datasets only provide information about socioeconomic status at the national or provincial level, which meant that all regions within a province were allocated the same HDI, resulting in a less precise socioeconomic status at the regional level. We, therefore, calculated a Revised HDI (RHDI), using data from local government papers, statistical yearbooks and the Nation Bureau of Statistics in order to better reflect the socioeconomic situation of regions where nature reserves are located, in other words, we attempted to downscale the resolution of the RHDI to reflect the actual, local socioeconomic conditions. Specifically, if a nature reserve was located within the footprint of a county, the resulting data for the three HDI dimensions was also at county level-resolution.

We then used Generalized Additive Models (GAMs) to determine the trends between human impact, socioeconomic status and the conservation effectiveness of nature reserves. To better explore links between conservation outcomes and RHDI, we split the 788 nature reserves into two groups based on the average RHDI value, and then employed GAM to show the links of socioeconomic status of overall nature reserves and corresponding species richness of Threatened species, Near Threatened species and Least Concern species, which was further differentiated by national nature reserves, provincial nature reserves and county-level nature reserves. We tested the normality of species richness of the two groups to determine whether t-tests or nonparametric tests (Mann-Whitney test) should be used.

## 2.6 Human impacts and age of nature reserves

Looking at the temporal dimensions of nature reserve establishment, potential biases might exist for example in initial establishments occurring in areas that are already sparsely populated and where societal ‘establishment costs’ are hence low. Alternatively, nature reserves might initially have been established in regions where species faced the greatest threats from anthropogenic pressures, which likely would result in them being established either in highly populated or relatively poor areas, instead. Either way, the temporal patterns of establishment might coincide and interact with socio-economic factors that we are targeting in this study. A Regression Discontinuity Design (RDD) is a pretest-posttest approach to estimate causal effects of treatment in a non-experimental setting by determining if an observed "forcing" variable exceeds a significance threshold in its influence (Lee & Lemieux, 2010). It focuses on the discontinuity at a pre-determined cutting off-point, observable by the direction and magnitude of potential discontinuities (jumps) of lines between two sides of the cutting-point. Any statistically significant discontinuity indicates a significant causal effect of the treatment (Yang et al., 2020). Thus, RDD can examine if there are significant relationships between human impacts and the age of nature reserves, reflecting any of the potential biases in nature reserve establishment.

Establishment years of nature reserves considered here ranged from 1972 to 2012, with the median year of 1992 set as the cutoff point for our RDD analysis. Nature reserves created prior to 1992 were classified as the control group, while those created after 1992 were classified as treatment group. We effectively tested the hypothesis that younger nature reserves were subjected to greater human impacts than older nature reserves due to increased establishment costs over time, including land acquisition, infrastructure development, ongoing management and maintenance, and opposition from local communities, which may result in the establishment of protected areas in more developed areas or those already heavily impacted by human activities. In this analysis, the Global Human Modifications dataset represented human impact, and we used the 'GAM' method in the 'rdrobust' package and the 'ggplot2' package in R to calculate and visualize the RDD results.

## 3. Results

### 3.1 Conservation status

The total of red-listed species under any threat category account for 13.6% of all evaluated mammal, 26.2% of evaluated amphibian and 11.7% of evaluated reptile species (Table 1).

**Table 1** – Conservation status of evaluated species from the selected vertebrate taxa in China

| IUCN category | CR | EN | VU | NT | LC | DD | EW | Total | % Threatened |
|---|---|---|---|---|---|---|---|---|---|
| Mammals | 10 | 40 | 41 | 38 | 474 | 67 | 1 | 671 | 13.6% |
| Amphibians | 6 | 30 | 41 | 16 | 165 | 36 | - | 294 | 26.2% |
| Reptiles | 9 | 15 | 15 | 7 | 251 | 37 | - | 334 | 11.7% |

Notes: CR- Critically Endangered; EN- Endangered; VU- Vulnerable; NT- near Threatened; LC- Least Concern; DD- Data Deficient; EW- Extinct in the Wild.

With regards to the inclusion of Threatened species' known distribution ranges' inclusion in China's most important PAs for biodiversity conservation, the picture varies greatly between different taxa. The distribution ranges of all 10 Critically Endangered (100%), of 39 Endangered (97.5%) and 37 Vulnerable (90.2%) mammal species are currently at least partly covered by the existing key nature reserves. This network also covers at least parts of the distribution range of 89.4% of all the IUCN-assessed Chinese mammal species (Table 2). In sharp contrast, the often extremely small distribution ranges of only 2 of the 6 Critically Endangered amphibian species (33.3%) are currently protected within the studied 788 nature reserves. The proportions look somewhat better for the amphibian species listed under the lower threat status, with the ranges of 19 (63.3%) Endangered and 30 (73.2%) Vulnerable amphibian species at least partly covered by the nature reserves network – while 66% of all amphibian species' distribution ranges covered by the PA network (Table 2). Reptiles occupy an intermediate position between mammals and amphibians, with the known distribution ranges of 6 of the 9 Critically Endangered (66.7%), 9 of 18 Endangered (50%) and 10 of the 15 Vulnerable reptile species (66.7%) at least partly covered by the investigated PA network – while 80.2% of the total assessed reptile species were covered by China's network of key nature reserves (Table 2).

**Table 2** – Number and proportion of assessed species – differentiated by IUCN threat status categories – whose distribution ranges are at least partly covered by China's studied protected area network.

| IUCN category | CR | EN | VU | NT | LC | DD | EW | Total |
|---|---|---|---|---|---|---|---|---|
| Mammals | 10 | 39 | 37 | 34 | 434 | 45 | - | 600 |
| (% of species) | (100) | (97.5) | (90.2) | (89.5) | (91.6) | (67.2) | (0) | (89.4) |
| Amphibians | 2 | 19 | 30 | 12 | 113 | 18 | - | 194 |
| (% of species) | (33.3) | (63.3) | (73.2) | (75.0) | (68.5) | (50.0) | | (66.0) |
| Reptiles | 6 | 9 | 10 | 6 | 213 | 24 | - | 268 |
| (% of species) | (66.7) | (60.0) | (66.7) | (85.7) | (84.9) | (64.9) | | (80.2) |

Notes: CR- Critically Endangered; EN- Endangered; VU- Vulnerable; NT- near Threatened; LC- Least Concern; DD- Data Deficient; EW- Extinct in the Wild.

Threatened mammals, reptiles, and amphibians are highly concentrated in the south and southwest of China's nature reserves network (Figure 3a). Near Threatened mammals, reptiles, and amphibians also showed a high concentration in southwestern China's nature reserves, with the diversity of these species contained in these areas generally decreasing from south to north (Figure 3b). The richness patterns for Least Concern species again closely resembles that of Threatened species, with a clear pattern of greatest species richness in the western sections of southern China (Figure 3c).

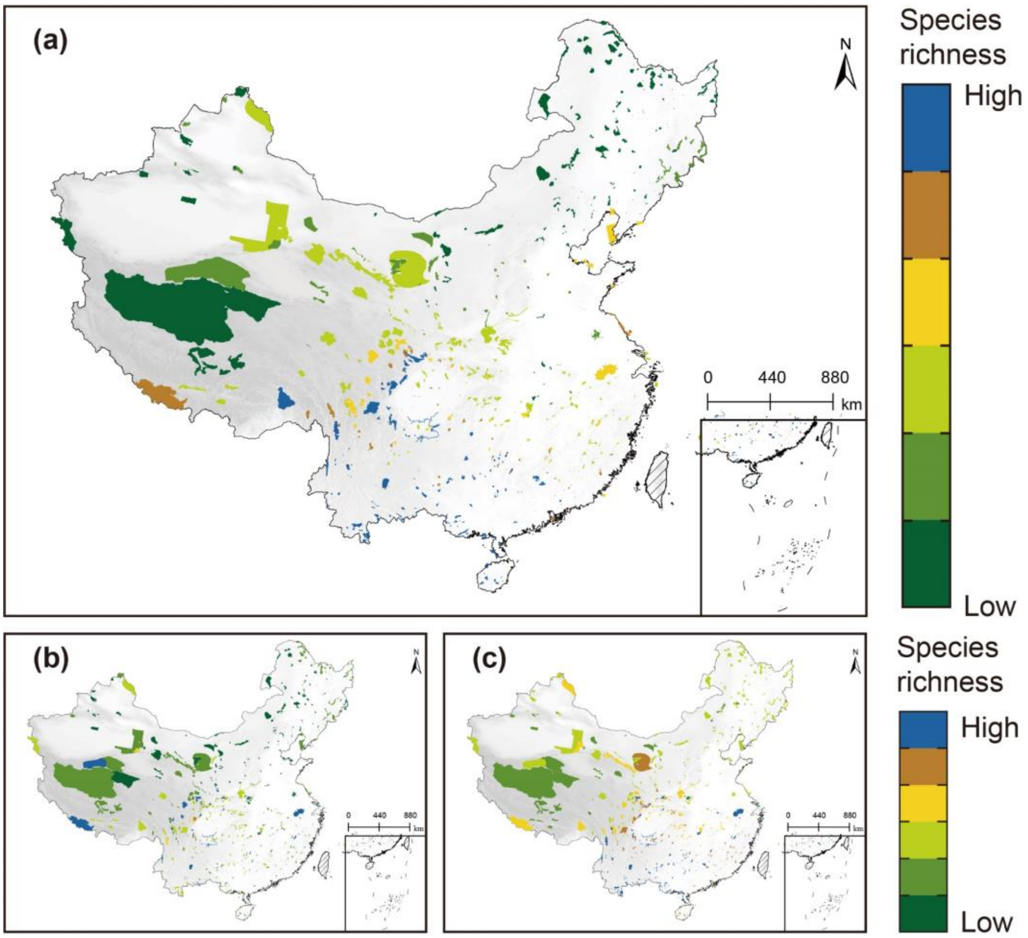


**Figure 3** Species richness within nature reserves in China. (a) Threatened species richness (b) Near Threatened species (c) Least Concern species richness

An additional analysis of the general species richness- nature reserves area relationship for all species showed no significant correlation, which are given in Supporting Information 2.5. Species' cover across the different nature reserves levels - national nature reserves, provincial nature reserves, and county-level nature reserves, indicated that for all Threatened species (Figure 4a), both national nature reserves and county-level nature reserves contained a greater species richness than provincial nature reserves, but, similar to patterns in Threatened mammals (Figure

4b), differences in species richness were minor. For Threatened reptiles and amphibians, national nature reserves performed better than provincial nature reserves and county-level nature reserves in protecting species (Figure 4c; Figure 4d), while provincial nature reserves and county-level nature reserves performed similarly well.

For -Near Threatened (NT) species, (Figure 4e), national nature reserves conserved more species than county-level nature reserves, but showed a similar conservation performance to provincial nature reserves. This trend was visible in species overall and in mammals (Figure 4f). For 'NT' reptiles, national nature reserves performed better than provincial nature reserves and county-level nature reserves, with little differentiation between these latter two categories (Figure 4g). The species richness of 'NT' amphibians (Figure 4h) was not significantly differentiated by the nature reserve level. Finally, for ‘LC’ species overall as well as for ‘LC’ mammals, no significant differences were again observed between the three types of NRs (Figure 4i; Figure 4j). ‘LC’ reptiles and ‘LC’ amphibians (Figure 4k; Figure 4l) in contrast showed a clear trend, with national nature reserves and county-level nature reserves outperforming provincial nature reserves.

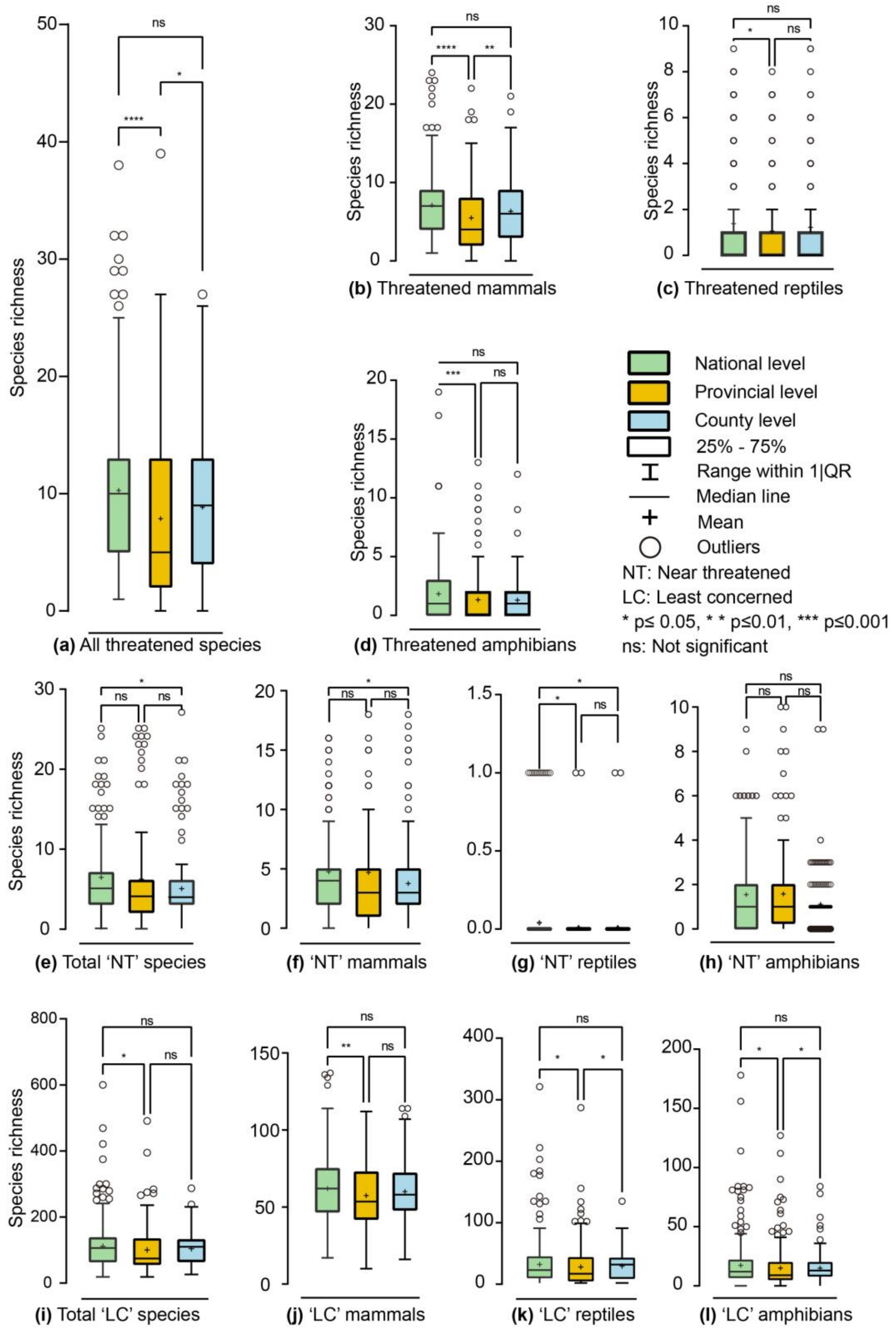


**Figure 4** Conservation outcomes of national nature reserves, provincial nature reserves and county-level nature reserves for three taxa based on IUCN Red List Categories.

### 3.2 Relationship between species and socio-economic factors

Nature reserves characterized by high RHDI values showed significantly better conservation outcomes than reserves with a low RHDI (Figure 5). Nature reserves with a high RHDI conserved more Threatened species (Figure 5a) than nature reserves with a low RHDI, a pattern that was particularly pronounced for RHDI values below a threshold of 0.7, with this trend being persistent across national nature reserves and county-level nature reserves (Figure 5d; Figure 5f), while the similar trend in provincial nature reserves was not statistically significant (Figure 5e). The value of 0.7 was generally observed as a turning point in many trends, and was hence used to differentiate low from high value nature reserves.

Nature reserves with a low RHDI in this context showed superior conservation outcomes for Near Threatened species (Figure 5b). These nature reserves generally conserved a greater number of 'NT' species than those with a high RHDI. This pattern was replicated for provincial nature reserves (Figure 5h), while no significant differences in conservation outcomes were found for national nature reserves and county-level nature reserves (Figure 5g; Figure 5i).

Nature reserves with a high RHDI in contrast showed superior conservation outcomes for species classed as Least Concern (Figure 5c). Nature reserves with a high RHDI therefore conserved a greater number of ‘LC’ species than those with a low RHDI. This situation was again present for both, national nature reserves and county-level nature reserves (Figure 5j; Figure 5l), while no significant differences were observed for provincial nature reserves with a low and high RHDI value (Figure

5k).

P-values of smooth terms for ‘NT’ species in the GAM models for national, provincial, and county-level nature reserves all exceeded 0.05 (see Table S1 in Supporting Information), indicating non-significant patterns in non-linear relationship between economic factors and species richness, and that an increase in the RHDI may not significantly impact conservation outcomes for ‘NT’ species in comparison to the other threat category groups. In contrast, the $R^2$ values of ‘LC’ species found in county- and provincial-level nature reserves were extremely high in comparison to other groups, suggesting that the effects of RHDI are specifically strong for ‘LC’ species encountered in lower-level nature reserves.

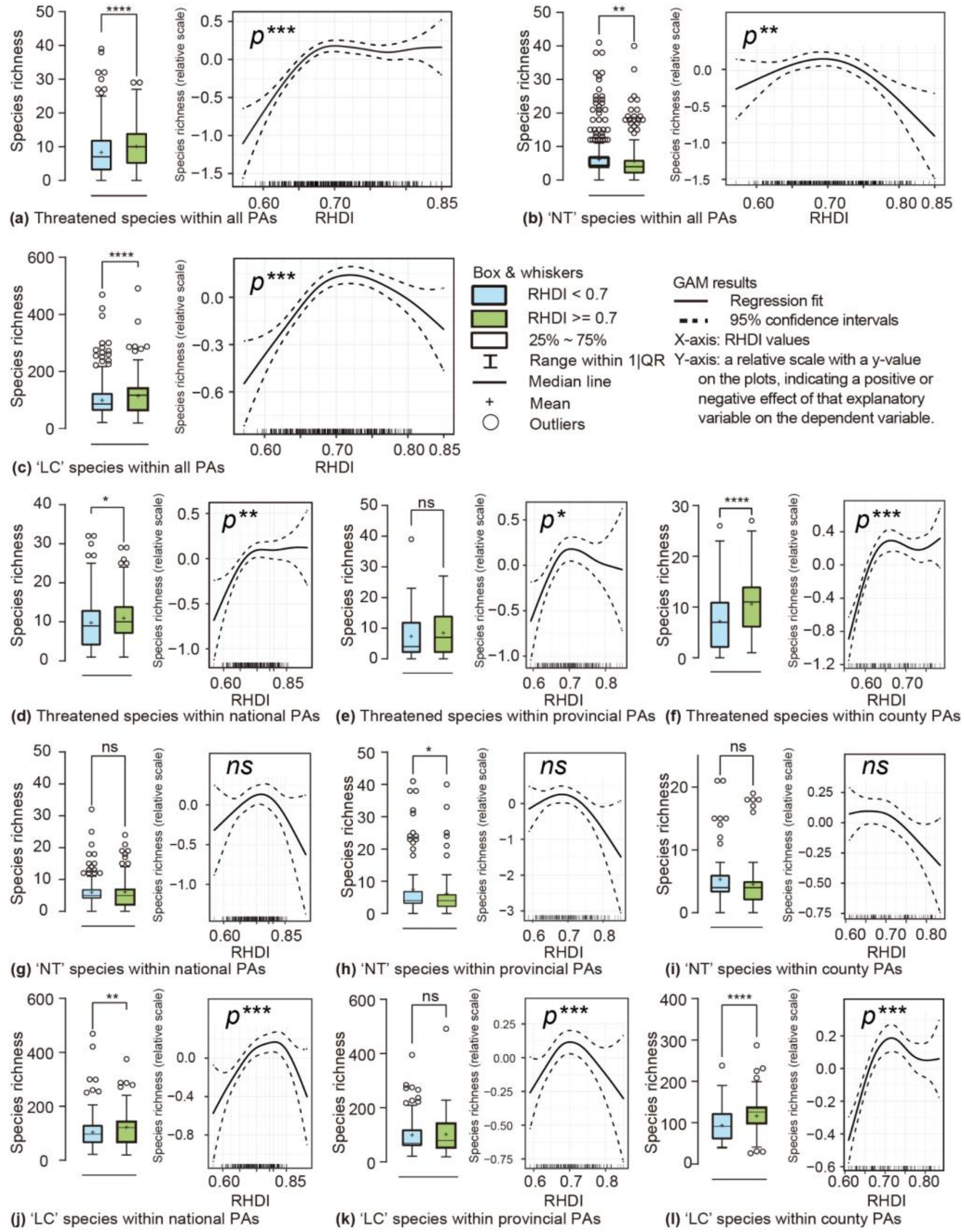


**Figure 5** Relationships between conservation outcomes (Threatened, Near Threatened and Least Concern species richness) and various nature reserves' socioeconomic status (RHDI within nature reserves) ('0' ; 0.001-'***'; 0.01-'**'; 0.05-'*'; ns-not significant)

### 3.3 Relationship between species and human impact factors

For all species, nature reserves with a high human effect showed worse conservation results than nature reserves experiencing a low human impact, and this trend was more pronounced within nature reserves with increasing GHM (Figure 6). More specifically, nature reserves' conservation outcomes for Threatened species (Figure 6a) grew with increasing GHM values between 0 and 0.3, but when GHM values surpassed 0.3, a contrasting pattern of diminishing species' coverage emerged, which became more pronounced with increasing GHM.

GAM results indicated slight fluctuations in the relationship between relative scale of species richness and GHM for Near Threatened species, while nature reserves with low GHM showed the best conservation outcomes (Figure 6b). For nature reserves with GHM values ranging from 0 to 0.2 conservation outcome increased with GHM, but once GHM values exceeded 0.2, a negative trend was observed, though there was a minor increasing conservation outcome with GHM values between 0.5-0.62.

The trend for species of Least Concern (Figure 6c), patterns resembled the increasing-decreasing trends in Threatened species, while nature reserves with GHM values ranging from 0-0.25 showed a positive relationship, and nature reserves with GHM values >0.25 a negative correlation between GHM value and conservation outcome.

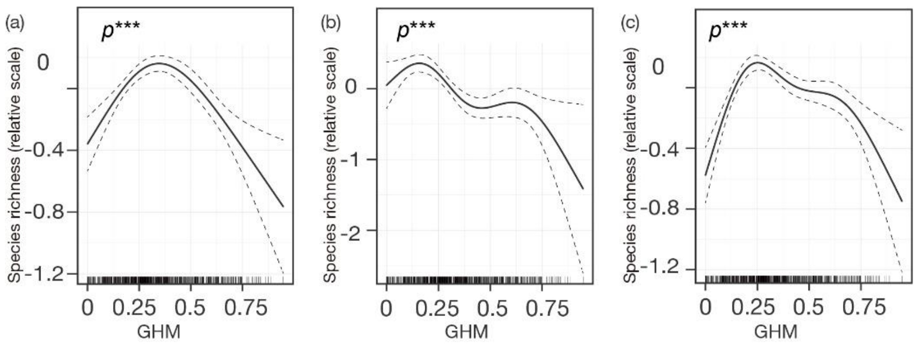


**Figure 6** Relationships between conservation outcomes (a) Threatened species;(b) Near Threatened species; (c) Least Concern species. X-axes designates average Global Human Modification values and Y-axes represents relative species richness values, indicating a positive or negative effect of that explanatory variable on the dependent variable.

### 3.4 Nature reserve age and human impact

The treatment group (nature reserves created after 1992) and the dependent variable (global human modifications) showed a significant negative relationship (see Table S3 in Supporting Information) . The estimate for the treatment group was -0.226 (standard error = 0.060), with a p-value < 0.001, indicating, in direct contradiction to our expectations, that nature reserves established after 1992 were characterized by lower levels of human modifications than those established prior to 1992.

The GAM model contained a smooth term for the centered variable indicating a non-linear relationship between the centered variable and human modifications (Fig. 7). The edf, ref.df, and F-values indicate that this relationship is statistically significant (p=0.001). This suggests that there is a non-linear relationship between the year of establishment of nature reserves and GHM that cannot be captured by the parametric term alone. Similarities between edf and ref.df values furthermore indicate that the smooth term did not overfit the data (see Table S3 in Supporting Information). The overall model had a low $R^2$-value of 0.046 and only explains 5.7% of the variations in the global human modification values of the nature reserves.

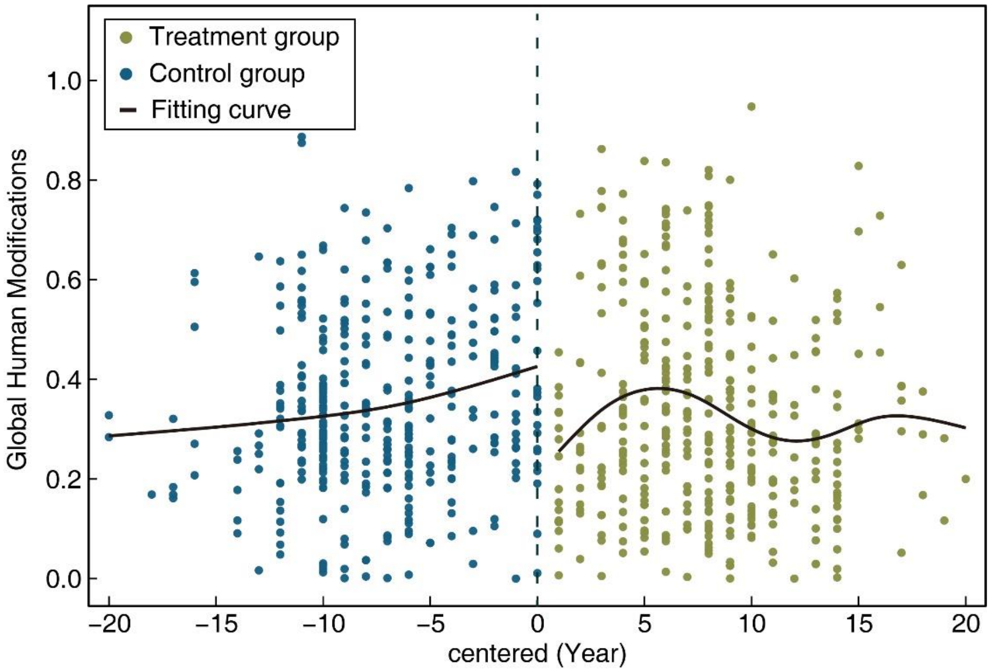


**Figure 7** Regression discontinuity plot of the effects of age on the Global Human Modification values of investigated nature reserves. The centered variables on the x axis were calculated by subtracting the actual year of NR establishment from 1992.

## 4. Discussion

Since 1956, China's PA network has rapidly increased and in 2020 covered ~ 18% of the total land area (Li & Pimm, 2020). The rapid expansion of China's PA network, combined with the enforcement of relevant legislation, is linked to favorable conservation outcomes for some iconic mammal species like giant pandas or Pere

David's deer (Li & Pimm, 2016; Zhang et al., 2021). For less charismatic reptile, and especially amphibian species with their commonly very limited distribution ranges, general trends appear much less favorable (Fey et al., 2015), also reflected by their much lower cover within the investigated nature reserves network. This pattern indicates that additional PA designations, or other, more holistic species conservation plans conserving for example entire mixed natural-cultural landscapes, are urgently required to secure their future survival. It is crucial to note, too, that the simple intersection of nature reserves with species' distribution ranges does not guarantee the effective protection of the respective species (Rodrigues et al., 2004). Instead, the actual size of nature reserves and of the populations of Threatened species they contain, the state of protected ecosystems, nature reserves' governance systems and associated sustained financial support of reserves, as well as the potential persistence of key threats causing original species' declines, strongly determine conservation outcomes (Campos-Silva et al., 2021; Geldmann et al., 2015; Watson et al., 2014), too.

Nature reserves currently planned or under construction are typically designated to protect a small set of specific species or a specific taxonomic group (Bohorquez et al., 2021). Nonetheless, as China increasingly puts a focus on the conservation of 'CR' species, our results indicate that some nature reserves designated, accordingly, may also serve the protection of a wider range of Threatened species. One example is provided by nature reserves in Guangxi designated to protecting gibbons (*Nomascus nasutus*). These receive direct funding from central and local governments, and are conserving not only two ‘CR’-categorized species, but more than twenty Threatened species, overall. Focusing on EOO results, it was in contrast surprising to discover that the proportions of overlap between ‘NT’ species and nature reserves among mammals, reptiles, and amphibians were relatively low, indicating that these species may have received limited attention, leaving them potentially exposed to risks pushing them into a Threatened state. Moving forward, a multi-taxon approach targeting areas of maximum distribution range-overlap in Threatened, and potentially also ‘NT’ species not already covered well in the existing PA network in our view would be a very effective approach, accompanied by the establishment of top-down protection strategies and the accurate recognition and monitoring on targeted species (implications on multi-taxon approach for effective conservation are given in Supporting Information 2.6). It furthermore should be noted that China’s nature reserves established in recent decades were not primarily located in regions with high human impact that may have resulted in strong losses of local biodiversity. Instead, new nature reserves were designated in areas of low human impacts compared to established reserves, potentially indicating that the implementation of area-based conservation measures was increasingly based on targeted species and overall biodiversity conservation.

Species richness is clearly influenced by linked effects of habitat requirements and human pressures on protected areas, with species for example adapted to alpine environments commonly thriving in nature reserves located in Qinghai and Xinjiang Provinces, where human impact, but also levels of development and wealth, are all generally low. For the majority of taxa in China, Southern and Southeastern Provinces, and in particular Yunnan, represent biodiversity hotspots, reflecting the abundance of resources and highly favorable subtropical/tropical climatic conditions (Yang et al., 2015). These general trends are paralleled by the high species richness across all threat categories in the respective nature reserves.

Since the establishment of the ‘Law on the Protection of Wildlife’ (hereafter ‘wildlife law’), the threat levels faced by many listed species appears to have decreased, with their populations stabilizing or even increasing, as their habitats within nature reserves have remained relatively intact (Huang et al., 2021). However, with China’s move toward an ‘ecological civilization’, certain flaws are becoming apparent. These include the narrow focus on red-listed species and associated, restrictive definitions of rare and Endangered species that widely disregard the vast majority of biodiversity taken up by invertebrate taxa. Many species excluded from red lists are hence still facing a significant risk of extinction, particularly where their distribution ranges are poorly aligned to that of charismatic species like giant pandas that absorb vast proportions of conservation attention and funding. Taxonomic ambiguities are also a key problem, resulting in insufficient protection due to conservation professionals’ inability to identify species, or an insufficient appreciation of the genetic diversity in species complexes that might result in species within such groups going extinct before their status as independent species has been established, as exemplified by giant salamanders (McCartney-Melstad & Shaffer, 2015; Turvey et al., 2018). Some challenges were addressed in the 2016 revisions of the wildlife law that applies a ‘conservation first’ principle to wild animals, while also aiming to increase public awareness of the need of conservation and advancing ‘ecological civilization’-principles. The amended law emphasizes the importance of protected areas for wildlife protection, and any human disturbances potentially jeopardizing the survival of wild animals are strongly regulated within protected areas (Koh et al., 2021). Over the last two decades, additional legislation governing wildlife, biosecurity, and environmental protection have further aided the conservation of China’s biodiversity (Fang et al., 2022). This legislation helps limiting the introduction and spread of alien species in nature reserves and supports the preservation of important habitats. This has led to further increases in population of charismatic species, and more generally in local biodiversity across China’s nature reserve network, in turn enabling nature reserves to increasingly play the anticipated, significant role in overall biodiversity conservation (Zhang et al., 2017).

Clear criteria for the establishment and management of nature reserves have further increased their effectiveness, but with high-level national and local, county-level NRs outperforming provincial-level NRs. The large size and clear boundaries of national nature reserves greatly aid their coherent management. Their high public profile also facilitates a lot of direct funding and surveillance from provincial and central governments, resulting in comparatively low levels of illegal activities (Song et al., 2020). In contrast, we believe the interest of local people in local biodiversity and their ecological knowledge may significantly contribute to the comparatively high conservation outcomes of county-level nature reserves. The reasons of county-level nature reserves' high conservation outcomes over provincial nature reserves are given in Supporting Information 2.7.

In addition to lacking the prestige and funding of national nature reserves and the local community links associated with many county-level nature reserves, the relatively low observed conservation efficiency of provincial nature reserves can additionally be linked to land ownership disputes and unclear, or ambiguous, conservation objectives that result from regional socioeconomic development disparities. Provincial nature reserves with boundaries spanning two or more provinces are traditionally managed by a plethora of different ministries and agencies, each potentially setting unique targets and applying distinct management standards for the PA area within their authority, resulting in poor or even conflicting conservation practices (Cao et al.,2013). Additionally, some provinces might prioritize economic development at the expense of the wider environment, resulting in neglected, poorly monitored and managed Provincial nature reserves. Collectively, these factors in our view might explain the relatively poor performance of provincial nature reserves reflected in our analysis.

The better performance of nature reserves in conserving mammals as compared to reptiles and especially amphibians might partly be explained by the easier identification of, and greater interest in mammals by non-specialists, which has aided advancement in wildlife legislation and assisted the timely establishment of the risk status and population trends of mammal species, in turn aiding the implementation of effective conservation measures and areas; however, this might lead to a bias toward documenting the occurrence of other species (Etard et al., 2020). As a result, mammal poaching and illegal selling is also relatively easy to notice and sanction once appropriate dedicated legislation and administration are in place. Reptiles, and particularly amphibians, are furthermore highly vulnerable to natural disasters, climate change (Brown et al., 2015) and, particularly in the case of amphibians, disease (Marino et al., 2022; Shaffer et al., 2015), with low dispersal abilities of many amphibian species resulting in highly localized distribution patterns that further cause a low species richness of amphibians in many PAs.

Where direct human interferences are concerned, high levels generally impede PA conservation performances, with also aligns with Geldmann et al. (2018)'s observations. An increased human influence inside PAs commonly exacerbates habitat loss and degradation, and to the depletion of natural resources, while it commonly leads to formations of movement barriers by infrastructure like roads, culminating in declines both in genetic diversity and population numbers of species within the PAs. In response, PA management and surveillance efforts, initially focused on national nature reserves, have subsequently been expanded to Provincial nature reserves and county-level nature reserves, with the target of prohibiting poaching and illegal human encroachment in nature reserves.

In support of hypothesis 3, we found positive links between socioeconomic status and Threatened species coverage of nature reserves. Poor education, local infrastructure and high reliance on natural resources in economically poor regions could explain this trend. Some residents living within or adjacent to PAs particularly in poor areas might hence opt for unsustainable natural resource uses, often resulting in greater overall poverty. In some nature reserves in areas with low socioeconomic growth in western China such as Tibet and Xinjiang Province, conservation outcomes in contrast were excellent, as locals had close relationships with nature and wildlife based on local traditional knowledge. In these areas, unsustainable use of natural resources and resulting an unfavorable conservation status seems chiefly linked to an influx of non-local populations lacking the local ecological-cultural understanding.

We see multifaceted processes linking socioeconomic factors to an enhanced conservation efficiency in protected areas. Enhanced investment, including central government funding, but also local and foreign funds, can be utilized to promote the establishment and management of PAs, but also associated activities like targeted conservation operations, research and monitoring, to ensure sustainable positive conservation outcomes.

Monetary factors also play a significant role in alleviating poverty among local communities residing within or near natural reserves, reducing pressures to extract natural resources from the protected areas. In the past, local residents have faced opportunity costs related to physical displacement or restricted access to their local natural resources. Resulting increased poverty risks and local hostility toward PAs can in these cases lead to refusals to collaborate in conservation. With economic advancements and associated local increases in sustainable, quality-focused production patterns, more stringent legal regulations have been successfully implemented in China's more economically developed areas that, in addition to the decreased reliance of local populations on direct natural resource extractions, has decreased pressures on natural habitats. As a result, habitat fragmentation and anthropogenic pressures decreased, reducing the risk of species' extinctions. Economic growth also had a significant impact on the environmental education and associated awareness of local communities, helping them understand the importance of conservation and emphasizing the importance of a sustainable resource use, resulting in more responsible uses of natural resources and a stronger sense of ownership and stewardship for the environment. Regional economic growth has also ensured better financial assistance and ecological compensation to local people and communities, further improving PA conservation performances. These laid the foundation for ecotourism, which can profit local communities via for example entrance fees and guide services that can also be used in direct support of conservation efforts, from actual conservation initiatives, required personnel, infrastructure improvements and other aspects of protected area management. Moreover, by providing alternative livelihoods and opportunities for income generation, ecotourism can play a key role in alleviating poverty and improving living conditions, strengthening the overall appreciation and good-will towards local nature reserves.

China's nature reserves, which will reach a higher socioeconomic level with a RHDI of 0.7 appearing to be the current cutoff, have a high potential to gain from improved well-being outcomes, income generation, the preservation of regional culture, the strengthening of local governance, land tenure, the protection of social rights, and improved access to natural resources (Campos-Silva et al., 2021). While nature reserves with a RHDI less than 0.7 had a high potential to profit from socioeconomic growth, as China's network of nature reserves became more socioeconomically developed, the threshold increased, resulting in a clearer relationship between socioeconomic growth and nature reserves' conservation of Threatened species. It is important to note, however, that 'LC' species showed a downward trend when RHDI exceeded values of ~0.7. This could be due to the relatively small species richness that some nature reserves conserved, or it could be that some regions reverted to unsustainable development practices, resulting in unfavorable land use changes, pollution, or the over-extraction of natural resources. Alternatively, or additionally, there might have been less overlap in the distribution ranges of taxa in the respective parts of our study area.

When looking forward, it is essential to also consider the interrelationships between global change, socioeconomic development, and the conservation effectiveness of nature reserves – highlighting the importance of holistic biodiversity conservation frameworks where area-based conservation efforts are complemented by landscape-scale approaches that also create migration opportunities for protected species allowing them to adapt their distribution ranges to altered climatic conditions. Urbanization furthermore is also regarded as one of the most significant global drivers of biodiversity loss – and often can be directly linked to increasing economic prosperity (Zhang et al., 2017). Urban expansions frequently result in the conversion of natural habitats to anthropogenic land uses in the form of housing developments, roads and similar infrastructure, resulting in the fragmentation and isolation of remaining natural habitat areas (Song et al., 2020), which negatively impacts on the viability of remnant, isolated populations. This was compounded in Africa, where the conservation of PAs has remained a contentious issue, with the establishment of PAs resulting in the eviction of residents and fostering mistrust among nearby rural Africans. (Kinzig & McShane, 2015). In addition, poorly managed urbanization can lead to increases in pollution, a modification of local climates via urban heat island effects and associated changes in the water cycle that further exacerbate warming trends caused by climate change. These were fairly typical problems for PA performance over the world, particularly in large human growth centers. PAs in South Asia, for instance, confronted a wide range of anthropogenic threats, such as forest fires, waste disposal, and illegal logging, necessitating conservation efforts linked to socioeconomic considerations (Chowdhury et al., 2022). A similar situation was also observed in West Africa, where it was essential to combine socioeconomic factors with conservation strategies to protect natural vegetation against agricultural expansion (Schulte to Bühne et al., 2017). On the other hand, a declining rural population brought on by urbanization may give rise to the perception of less negative effects on nature and, consequently, more promising prospects for conservation and restoration (Sanderson et al., 2018). From a more upbeat viewpoint, increasing prosperity linked to urban centers could lead to more funding and infrastructure for biodiversity conservation, too - exploring types of protection that better integrate local actors and stakeholders (Geldmann et al., 2019), supporting the management and protection of local nature reserves and species habitats, as well as better environmental education opportunities with the benefits outlined above.

Overall, China's PAs network expanded considerably following the country's joining of the CBD in 1992, while PAs have been expanded further not least in response to the SDGs (Sustainable Development Goals)' 14 and 15 criteria. China is now trying to address concerns associated with the original establishment of PAs, including ecological compensation schemes, management of resulting human-wildlife and land conflicts, while continuing to transition to a more sustainable economic development model and the deepening of the ecological civilization ethos amongst its population (Wu et al., 2019). In combination with the ongoing rural-urban migration, these developments will hopefully also decrease economic disparities within the country, and hence increase the conservation outcomes by decreasing direct anthropogenic pressures across China's PA network.

With the strong research focus on ecosystem services over the last few decades, the livelihoods and economic and cultural status of local communities living within and near nature reserves in general is receiving increased attention, in many cases positively affecting local citizens' attitudes toward PA establishment and conservation. Eventually, the aim has to be to create conditions that allow economic growth and conservation to progress in lockstep. Additionally, it seems imperative to strongly develop also more holistic conservation approaches supplementing area-based conservation that incorporate both cultural as well as natural habitats and their management at large spatial scales, such as China’s ecological ‘Red Lines’ in safeguarding China's vast biodiversity, environmental resources and ecosystem services (Sang & Axmacher, 2016), in turn providing more permeable landscapes that allow species to effectively respond to changes in climatic conditions, as well as other, local environmental and anthropogenic pressures.

China's PA network benefits conservation outcomes for Threatened mammal species, and, albeit to a lesser degree, also its Threatened reptiles and amphibians, with both high socioeconomic development and low levels of direct human influence improving conservation outcomes. This indicates that, once local populations do not need to extract large amounts of natural resources from their local environment, local conservation and socioeconomic development might be able to advance in lockstep. China's economic development is increasingly allowing local authorities to address livelihood concerns of residents within and in the vicinity of PAs, in turn significantly altering their attitudes toward these areas and conservation activities as ecological compensation and ecotourism initiatives are implemented. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2019 has called for a paradigm shift in the global economic system to address biodiversity loss (IPBES, 2019). In line with its ‘ecological civilization’ framework, China is approaching this challenge in trying to shift its economic patterns away from ‘high-speed’ quantity-focused toward sustainable and more quality-focused development patterns.

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