

that risks encouraging a black market and smuggling operations like the ones that Prokopi got involved in.

Mongolia is particularly rich in fossils, especially in the Gobi Desert, where they have been well preserved and aren't at any immediate risk. Awareness of the inherent value of this heritage is still low, which has enabled illegal trafficking in the past.

Bolortsetseg (Bolor) Minjin, a Mongolian paleontologist who drew the attention of the Mongolian authorities to the illegal dealing with *T. bataar* skulls in the Prokopi case, has since helped to repatriate more than 30 dinosaur specimens that had been taken out of Mongolia illegally. She also works to raise the awareness among young Mongolians with the aim that in the future the wealth of fossils found in the Gobi Desert can be comprehensively studied, displayed and appreciated within the country.

For this purpose, she set up the non-profit Institute for the Study of Mongolian Dinosaurs. Its outreach work includes the running of a mobile museum that tours Mongolia as well as training and education workshops. Its long-term plan is to establish an education and research centre in the Gobi Desert, for which it is currently scouting a location.

It appears ironic that dinosaurs are getting too little attention in a fossil-rich country like Mongolia, whereas in the Western world some of the problems arise from the fact that they are getting too much attention. Paleontologists will have to find a middle way. As some have pointed out after the sale of Stan the *T. rex*, publishing research on privately owned fossils may well contribute to fuelling the hype and inflating their market value. The SVP is already discouraging academics from studying fossils held in private hands without a guarantee of permanent public access.

Also, there are beautiful fossils of many other living things, from the first land plants to recent extinct species like the woolly mammoth. If you feel the need to have a piece of evolutionary history in your home, it doesn't always have to be a *T. rex*.

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## Essay

# How China expanded its protected areas to conserve biodiversity

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How has the global network of protected areas developed — and which decisions have guided this development? Answering these questions may give insight into what might be possible in the next decade. In 2021, China will host the Convention of Biological Diversity's Conference, which will influence the coming decade's agenda. We consider how China expanded its protected areas in the last half-century. Did concerns about biodiversity protection drive those decisions, or were other factors responsible? Like other countries, China has protected remote places with few people that are unusually cold or dry or both. Despite that, species with small geographical ranges that have the highest risk of extinction are better protected than expected. Importantly, while the growth of total area and number of protected areas has slowed for the last decade, increases in protection of forested ecosystems and the species they contain have steadily increased. China's future reserve expansion must consider where to protect biodiversity, not just how much area to protect.

Expanding protected areas is the principal strategy to counter increasing human pressure on ecosystems and biodiversity [1–3]. The Convention of Biological Diversity's 2010 Conference of the Parties (COP 10) set goals for the following decade, known as the Aichi targets. For instance, Aichi target 11 seeks to protect an “ecologically representative” 17% of the land surface [4], while target 12 aspires to prevent the extinction of “known threatened species”.

Ambitious post-2020 goals to safeguard the disappearing biodiversity and threatened ecosystems include protecting 30% of earth by 2030, and programmes called ‘Half Earth’ [5] and ‘Nature Needs Half’ [6] that seek to protect half the land surface. These would lead to very substantial increases in the amount of area to be protected. They beg two questions: how successful has protection been thus far in protecting biodiversity? What more might protecting 30% or 50% of the land achieve?

Many studies have examined the efficacy of current protected areas at protecting biodiversity. Countries have generally protected sparsely populated, arid and high-altitude biomes disproportionately, while far more species live in forest biomes [1]. Thus, targets referring to total area protected can mislead. They

may encourage the expansion of protected areas into places with low human impact, but which achieve little extra biodiversity protection. ‘More of the same’ — protecting the less populated half of Earth — would add little to the portfolio of species protected [2]. Despite this — and quite surprisingly — the global network of protected areas is more effective at protecting the most vulnerable species than one would expect based on area alone [2].

Questions remain of how protected areas developed — and which decisions guided this development. Answering these questions may provide insight into what might be achievable in the next decade. In 2021, China will host COP 15, which will influence the coming decade's agenda. In this essay, we consider how China has expanded its protected reserves in the last half-century. Did concerns about biodiversity protection drive those decisions, or were other factors responsible?

China is home to exceptional biodiversity, thus making for a good case study. Its ecosystems range from permanent ice fields to tropical moist forests [7]. China is home to 14% of the world's bird species, 13% of mammals, nearly 11% of vascular plants [8,9], and 18% of fish [10,11] — far more than most countries in similar latitudes [12].



Facing confrontation from economic development, China has experienced dramatic environmental changes [13]. Nonetheless, it has engaged in domestic and international efforts to conserve biodiversity, including the commitment to expand protected areas [14].

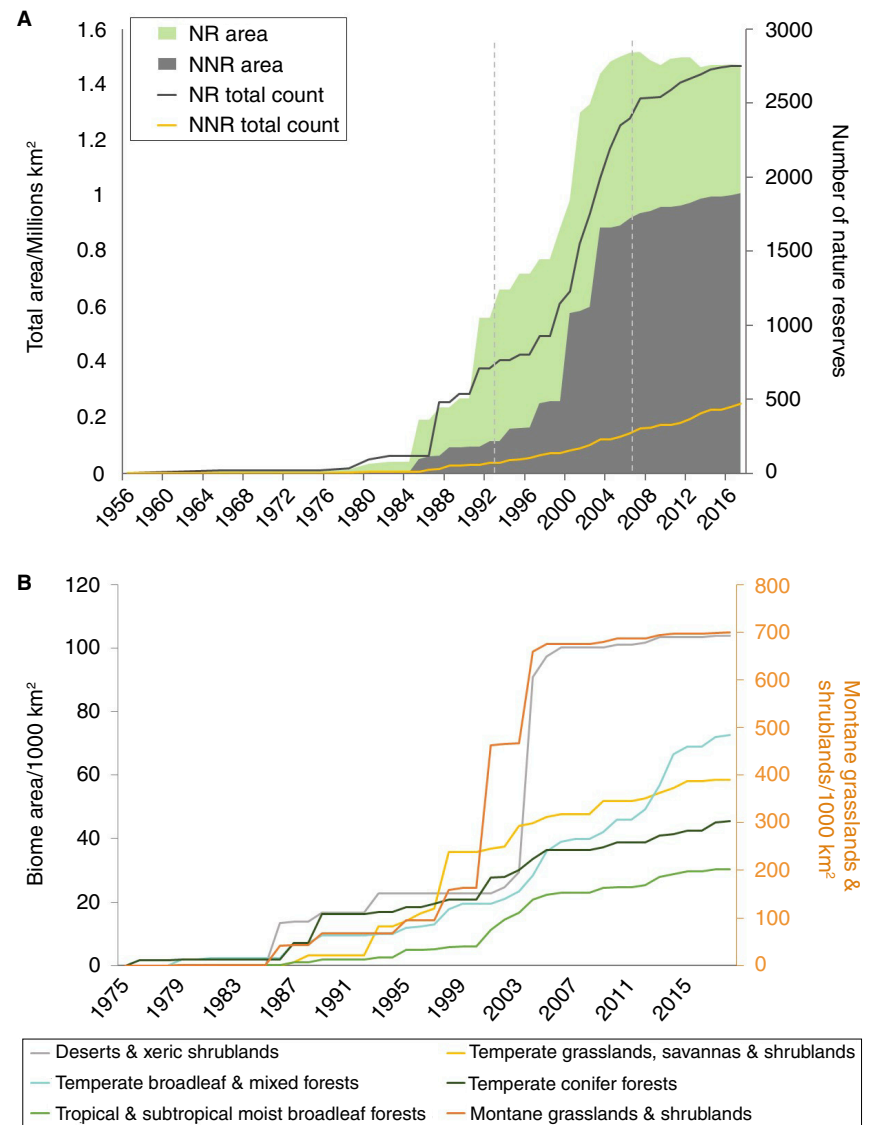
We ask three key questions: first, how successful has China's reserve system protected its biomes, ecoregions and species? Second, given the differences in the fractions of areas protected, are some taxa better protected than others? For instance, are vulnerable species protected better than expected? Our analyses include the species that IUCN deems threatened with extinction. We also considered species with small geographical ranges, including those endemic to China, and those that have more extensive ranges outside it.

These two questions are familiar in the conservation literature. Answering them requires only a 'snapshot' of a protected area network. By contrast, few studies address our third question: how does protection improve over time? Answering this question requires more effort, but uniquely it addresses whether progress is haphazard or moves towards the aspirations of the Aichi targets. Only by considering changes over time can we understand what might be possible for post-2020 conservation planning.

### Development of China's protected areas

China now has more than 11,800 protected areas, covering >18% of its land area [15]. These include 11 pilot national parks established in the last three years. The reform of the state administrations and new policies also encourage innovative forms of protection [16]. These include land trusts and community protected areas that were not possible ten years ago. Before that, the government was the only qualified management entity [13].

Among China's various kinds of protected areas, the nature-reserve system predominates. It has two levels. Local nature reserves are administered at the provincial, municipal and county level, while national nature reserves have better funding, permanent staff, clear delineation of boundaries and



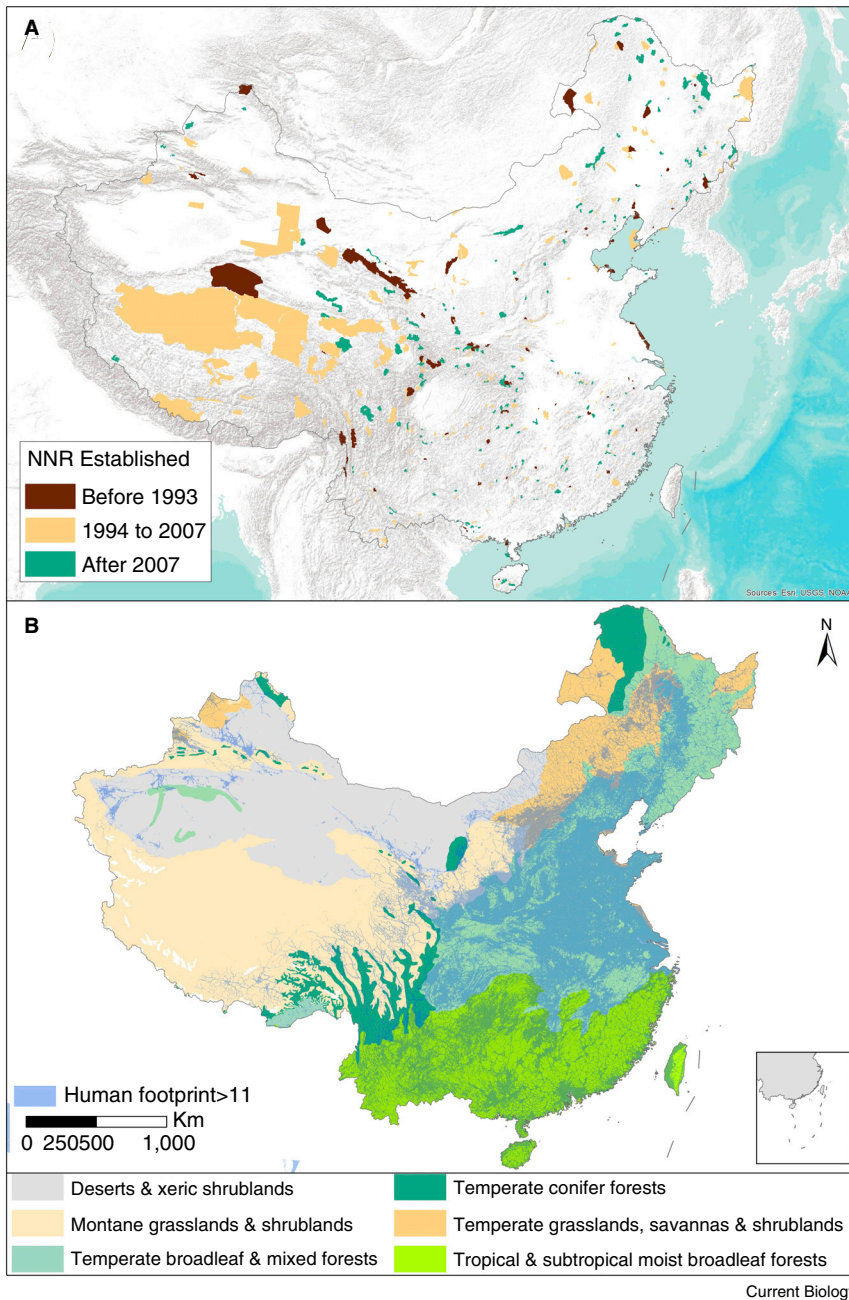
**Figure 1. Growth of protected areas.**

(A) Coverage (solid shading) and the number of nature reserves (lines) established in China from 1955 to the end of 2013. It shows both the national level (grey shading, orange line) and local level nature reserves (green shading, black line). The vertical dotted lines divide the time into three periods: the emerging period (before 1993), the rapid development period (1994–2007), and the adjustment period (after 2008). (B) Distribution of National Nature Reserves over the period. We employ a different scale for montane grasslands and scrublands because the largest reserves occur there.

independent administration [7,13]. Many of these nature reserves are also listed as 'key biodiversity areas', contributing to a network in China that includes 616 key biodiversity areas as of 2020 [17].

From 1956 to 2017, the expansion of protected areas was divided into three periods driven mostly by domestic policies and the commitment to international conventions. By 1993,

China had protected 6.7% of its land, 1.1% in national nature reserves. By 2007, these numbers had increased to 15.2% and 9.5%, respectively, and by 2017, to 14.9% and 10.2%. The number of national nature reserves had increased from 71 to 303 to 469 by the end of 2017. The substantial increase in reserve number in the latter period, but not the total area, reflects an increase in small reserves



**Figure 2. Distribution of protected areas.**

(A) A map of the national nature reserves colour-coded by the periods of their establishment. Area in grey represents terrain relief. (B) The distribution of six major biomes discussed in the text, with underlying shading to show areas with a human footprint index >11.

and downsizing and degazettement (removal of legal status) of existing reserves [18]. Nature reserves in regions with rapid economic growth have experienced a higher decrease in area [18]. While there were over 400 local reserves degazetted over the past few decades, no national nature

reserves have been degazetted. This suggests that national level reserves are more effectively managed than local ones [18].

There are no accepted guidelines for identifying priority and representative areas to conserve [19]. Most regions and countries use species richness or

some representation of broad habitat types as the planning targets [20]. We assess the success of protecting biodiversity in three ways.

First, to understand broad patterns of diversity, we examined 61 of China's ecoregions [21]. We calculated the changes in fractions of them the national nature reserves cover and identified 'gap ecoregions' — those not encompassed by the reserve system.

Second, we compare the protected fraction of the geographical ranges of 2062 species of bird, mammal and amphibian against the null expectation — that is, a planning process assigning national nature reserves randomly without regard for species distributions. Of particular concern are those species with the smallest ranges, as they are most vulnerable to extinction. Have these been protected better or worse than expected? And has the reserve system protected some taxa better than others? Third, a valuable tool to track the changes is GAP analysis [22]. We call species that are not covered by protected areas 'gap species'.

For 1956 to the present, we show the total area and number of all nature reserves (Figure 1A). For analytical convenience, we divide this history into three intervals.

**The emerging period before 1993**

China created its first nature reserve in 1956, and the first national-level status was given in 1975. The number of reserves increased thereafter, despite the interruption during the Cultural Revolution 1967–1978. By 1993, China had created 763 nature reserves, covering 7.1% of China and including 71 national nature reserves covering 1.4% of China. During this period, China passed several laws related to environment and conservation, including the Forest Law (1979), Law on the Protection of Wildlife (1988), and the Environmental Protection Law (1993) [23]. China ratified the Convention on Biological Diversity and became a contracting country on the Ramsar Convention.

**The development period: 1994–2007**

In 1994, China published the first law on protected areas — 'Regulations of the People's Republic of China on

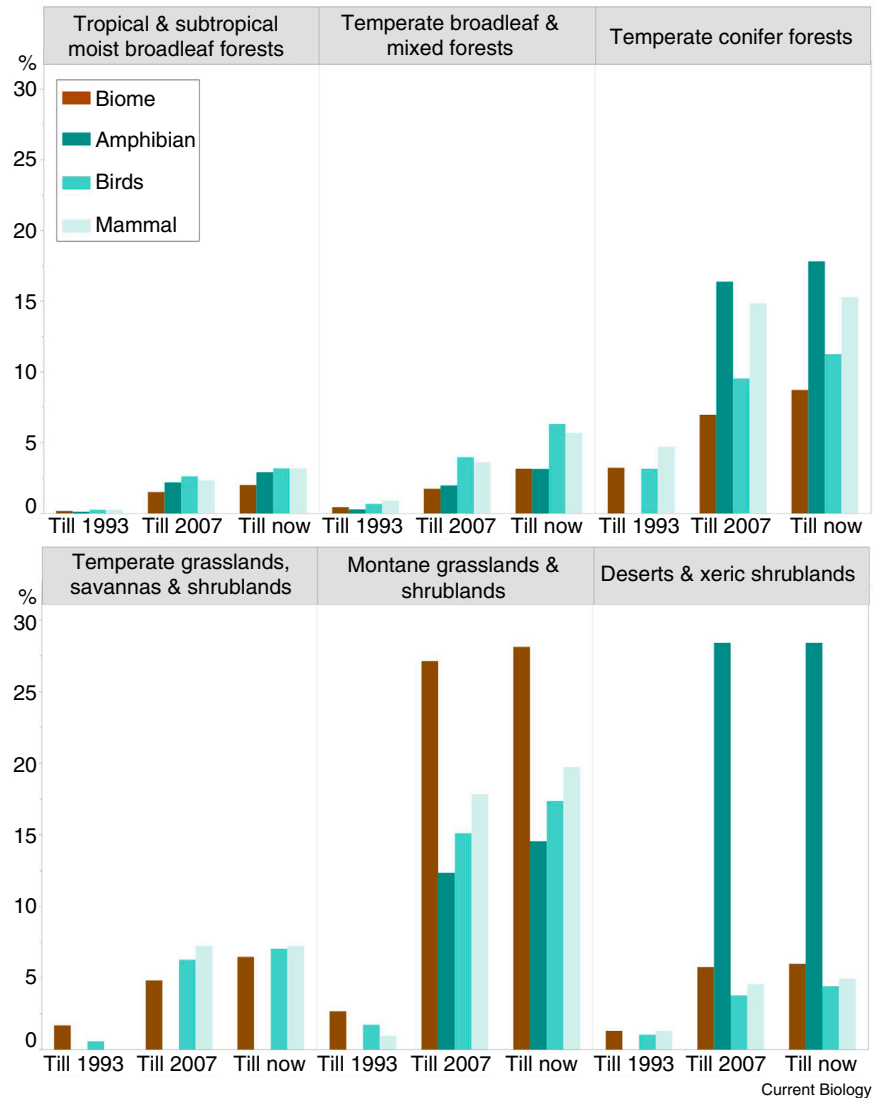
Nature Reserves'. It marked a new period with rapid expansion resulting in 2531 national and local nature reserves by 2007, covering 16.2% of the land area; national nature reserves covered 10.1% of China.

**The adjustment period: the last decade**

We separate this decade because it provides the best insights into what the next decade may achieve. It also differs from the past. The increase in reserves slowed after 2008, reaching 2750 reserves covering 15.7% of China by the end of 2017. In this period, conservation planning and priority setting has been promoted to design new protected areas, leading to a more top-down approach and purposely addressing some problems from regional or national scale. China has emphasised environmental protection. This emphasis includes China's new blueprint for an 'ecological civilisation' [24], ecological redline policies to delineate areas to secure ecosystem services [25], and creating the national park system [26].

The growth rate in numbers of national nature reserves has remained essentially constant since 1984 at a rate of 16.6 reserves per year. Reserves established in recent years (2008–now) were of small size, contributing less than 1% increase in the total coverage. The total coverage of national nature reserves by 2017 reached 11% of China (Figure 2A). The 61 ecoregions can be grouped into six major biomes. The largest reserves are in the drier, open regions rather than in the forest ones. They are also regions with a lower human footprint (Figure 2B).

During the second period, China expanded its protected area through large reserves. It created eight of the ten largest reserves during this period, mainly in western China. Like other countries, the largest reserves are in high-altitude or arid places with low human population density [1]. Because of this rapid and extensive expansion of reserves in open habitats between 1998 and 2003, the overall pattern is that the growth of total protected area and area of national nature reserves have slowed considerably since (Figure 1A). This overall slowing hides the fact that the areas of protected



**Figure 3. Extent of species and biome protection in China.**

The figure shows the percentage of each biome protected and the median percentage of each species protected within each biome, for each of three periods, and the six major biomes analysed. For instance, about 3% of temperate coniferous forests were protected. By 1993, rising to 7% by 2007, and 8% now. For mammals in this biome, half of all species (the median) had 4.7% or more of their ranges protected in 1993. The percentage rose to 14.8% in 2007 and 15.3% now. Table S1 provides data on 25% quartiles, medians, and 75% quartiles.

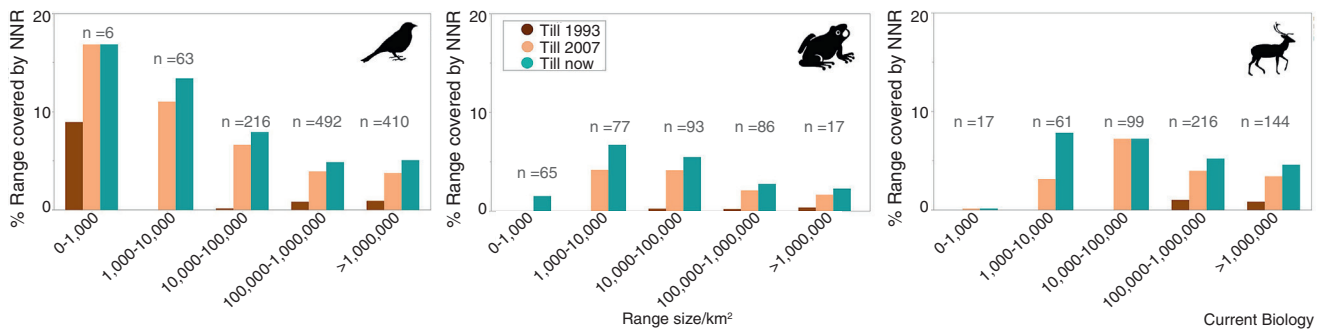
cold, tropical and subtropical moist forests have expanded continuously (Figure 3). Moreover, the protected area of temperate broadleaf forests has grown rapidly since 2008.

**Biomes and ecoregions**

In general, open habitats were better protected than forest ecosystems, resulting in 17.3% of grasslands, shrublands and deserts protected by 2017. Tropical and subtropical moist broadleaf forests were least protected

by national nature reserves, followed by temperate broadleaf and mixed forests (Figure 3).

These differences reflect different human use, which we can measure with the human footprint index [27]. The index scales from 0 to 50; roughly half of the global land surface is sparsely inhabited and has an index value of  $\leq 3.3$  [2]. For the six major biomes, the temperate broadleaf and mixed forest biome had more than 64.4% of the area under very



**Figure 4. The median percentages of ranges protected for birds, amphibians, and mammals for each of the three periods.**

Generally, reserves protect a higher fraction of species that have small geographic ranges within China. Table S2 provides data on 25% quartiles, medians, and 75% quartiles.

high human pressure, with a human footprint index  $>11$ . The tropical and subtropical moist broadleaf forest biome follows with 43.6%, then temperate grasslands, savannas and shrublands with 33.0% and temperate conifer forests with 13.4% (Figure 2B). Montane grasslands and shrublands, as well as deserts and Xeric shrublands, had less than 10% of the biome under high human pressure.

National nature reserves expanded mostly through the areas with low human pressure. However, the tropical and subtropical moist forest biome, the biome with the second-highest human pressure, experienced a similar or even higher increase in national nature reserves in its regions.

By 1993, there were no national nature reserves in 25 of the 61 ecoregions. The number declined to nine by 2007, and seven ecoregions still lack such reserves. All are at national borders. The average percentage of coverage for ecoregions increased from 1.6% in 1993 to 9.1% in 2007 and 10.1% now. These are close to what one expects by chance, given a random allocation of reserves across ecoregions.

### Species

Reserves protect biomes to different extents and biomes hold different numbers of species. Some 36.2% of bird species, 38.0% of mammal species and 60.7% of amphibians predominantly live in tropical and subtropical forests, the biome with the highest number of species (see Supplemental Information for the selection of species and data sources).

Over all biomes, amphibians have a relatively lower percentage of coverage of their ranges by national nature reserves than birds (Wilcoxon test,  $Z = 4.55$ ,  $p < 0.001$ ) and mammals (Wilcoxon test,  $Z = 2.90$ ,  $p < 0.01$ ). With a median range of 5.7% and 5.3% of birds and mammals protected, it was only 3.1% for amphibians. (Details of the 25% and 75% quartiles of these distributions are in the Supplemental Information.)

For almost all periods and all three groups, species were protected better than one would expect by chance given how much land each biome protects (Figure 3). The conspicuous exception involves montane grasslands and shrublands — the best-protected biome. By 2007, reserves protected  $>25\%$  of this biome, but the median range sizes protected ranges from 14.6% for amphibians, 17.4% for birds to 19.7% for mammals. These are the highest medians across all biomes, yet they are smaller than the expectation.

By 1993, 157 bird, 118 mammal, and 156 amphibian species — 13%, 22%, and 46%, respectively — were gap species whose ranges lay entirely outside of the national nature reserve network. The percentages of gap species dropped dramatically by 2007 to 2%, 7% and 20%, respectively, then to 1%, 7% and 16% now. With about 35% of all national nature reserves established between 2008 and 2017, the improvement in reducing the number of gap species was small.

We notice the paradox of the amphibians. They have much smaller geographical ranges than birds and mammals [28]. Within the national

nature reserve network, they have a larger fraction of their ranges protected, but a much larger fraction of species is not protected at all. With small ranges, small protected areas can completely encompass some species but leave others completely unprotected.

The third pattern is that the reserves were more efficient at protecting the species that IUCN deems threatened than non-threatened species for mammals (Wilcoxon test,  $Z = 3.44$ ,  $p < 0.01$ ), with a median of 7.64% protected range for threatened species and 4.94% for non-threatened species. A similar pattern existed for birds but was not significant. Non-threatened amphibians had a slightly larger proportion of range protected (3.5%) compared to the threatened ones (3.85%) (Wilcoxon test,  $Z = -1.40$ ,  $p > 0.1$ ).

The fourth pattern is that, generally, reserves protected species with small geographical ranges better than those with larger ones (Figure 4). These species either are endemic or have limited ranges in China. The limited distributions make them more vulnerable to extinction, and so this result conflates the previous pattern. Some species of mammals and amphibians with very small ranges are not protected at all. IUCN classifies most as 'Data Deficient'.

### How successful has China been?

By 2017, China had protected 18% of its land in some form, and environmental redlines protect other areas to some extent. It has met the Aichi target 11's 17%. As we stress here and elsewhere [2], targets based

on area are misleading. This overall percentage conflates large protected areas in montane grasslands and shrublands with very low percentages of protection for particularly temperate and tropical forest ecosystems (Figures 2 and 3). These ecosystems hold the highest numbers of species, so the problem is acute. Compared to montane grasslands and shrublands, deserts and xeric shrublands were less protected even though these regions had a low human density (Figure 3). In short, China may meet Aichi's target 11 in terms of area, but protection falls short of being 'ecologically representative'. As elsewhere, it has proven easier to protect areas where few people live. At the level of its 61 ecoregions, China protects most of them to varying degrees, the exceptions being those on its frontiers.

Given these overall biases, how does China protect its biodiversity within biomes? Is it moving to meet Aichi Target 12 of preventing extinctions in doing so? The answer is consistently better than one might expect at random. On average, the fraction of a range protected should be independent of its size. A species that occurs over every part of China must have the same fraction of its range protected as does China, say 18%. At the other extreme, consider very small ranged species uniformly scattered across China. One would expect 18% of those species to be protected in their entirety but the other 82% to be not protected at all. Given this, how should we expect things to not be at random? More reserves are in remote places, where typically there are fewer species, and they have larger ranges (Figure 5). Thus, one might expect that fewer than expected small ranged species would be protected. Our results are the reverse of this, and we find that surprising.

Our results show that the median percentages of species ranges protected generally exceed the average percentage of the biome protected (Figure 3). The exceptions are the well-protected montane grasslands and shrublands, where species are best-protected, but less so than expected. China's protected areas have also helped protect the



**Figure 5. Protected areas and species in open habitats and forests.**

Large areas of the Tibetan plateau were among the first areas China protected, including Sanjiangyuan, which became a National Nature Reserve in 2003. It has an area of 363,000 km<sup>2</sup>. This and other long-established protected areas of the plateau hold more than 50% of the one million km<sup>2</sup> range of the Chiru (*Pantholops hodgsonii*), seen here at Qiangtang National Nature Reserve, Tibet. In contrast, the golden snub-nose monkey (*Rhinopithecus roxellana*) lives in the mixed deciduous broadleaf and coniferous forest of the mountains of southwest China. It has a range of about 100,000 km<sup>2</sup>, of which about 15% is protected, most since 2007.

most vulnerable species — small-ranged species are generally better protected than large-ranged ones (Figure 4). Very few species are now gap species — those that fall entirely outside protected areas.

There are differences between taxa and amphibians are less protected

than birds and mammals, as their median protected ranges are 3.8%, 5.7% and 5.3%, respectively. Amphibians have larger fractions of gap species, similar to the previous findings with endemic species [5]. Amphibians are less studied compared to mammals and birds, which leads

to a lack of information on amphibian species and their ranges. This pattern has partly contributed to the underrepresentation of amphibians. In China, more regional scientific studies correlate with improvements in species protections [29].

How has protection developed? Of course, as more areas are protected, then more of species' ranges and biomes will be protected on average. The timing is interesting. A superficial inspection based on the total area would suggest significant progress from 1994 to 2007, but little since. This result is also misleading. There has been a steady and continuous increase in the areas of protected forests and the fractions of species protected with them.

Overall, from 2008 until now, there was a just under 1% increase of the area of national nature reserves. Increases in coverage of temperate broadleaf and mixed forests, temperate conifer forests and temperate grasslands, savannas and shrublands were higher: 1.4%, 1.7% and 1.6%, respectively. Although tropical and subtropical moist broadleaf forests only had a 0.5% increase in the nature reserve coverage, all vertebrate taxa were much better protected than the biome average (Figure 3). In particular, small-range species benefited more from the expansion of nature reserves in the period from 2008 until now (Figure 4).

China hosts COP15 in 2021, which aims to reach an agreement on the post-2020 global biodiversity framework. At the World Park Congress in 2014, China promised to increase its terrestrial protected area coverage to 20% by 2020. The spatial planning of these increments is crucial to improving conservation planning and to provide the most cost-efficient way to balance nature and development.

China has been fortunate in the past in that many important areas for biodiversity are in its west, the least populated parts of China, and home to the charismatic giant panda. It has proven to be an effective umbrella for China's other endemic species [2,7]. Expanding protected areas in the sparsely populated west is possible: deserts and xeric shrublands still have

few national nature reserves (Figures 1 and 3).

Apart from these western areas, the density of human settlement will constrain reserves to be small elsewhere. The steady progress of protecting forest biomes and their species in the last decades should encourage China to do more of the same. In particular, tropical forests need better protection. The recent reorganisation of the management of protected areas in China affords the opportunity to continue the progress of making protected areas more representative of biodiversity [16].

#### SUPPLEMENTAL INFORMATION

Supplemental information contains supplemental methods and two supplemental tables and can be found with this article online at: <https://doi.org/10.1016/j.cub.2020.09.025>.

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