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The Value of Ecosystem Services from Giant Panda Reserves

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Keywords:

cultural service, ecosystem service value, giant panda, nature reserve, provisioning service, regulatory service

SUMMARY

Ecosystem services (the benefits to humans from ecosystems) are estimated globally at $125 trillion/year [1, 2]. Similar assessments at national and regional scales show how these services support our lives [3]. All valuations recognize the role of biodiversity, which continues to decrease around the world in maintaining these services [4, 5]. The giant panda epitomizes the "flagship species" [6]. Its unrivalled public appeal translates into support for conservation funding and policy, including a tax on foreign visitors to support its conservation [7]. The Chinese government has established a panda reserve system, which today numbers 67 reserves [8, 9]. The biodiversity of these reserves is among the highest in the temperate world [10], covering many of China's endemic species [11]. The panda is thus also an "umbrella species" [12] - protecting panda habitat also protects other species. Despite the benefits derived from pandas, some journalists have suggested it would be best to let the panda go extinct. With the recent downlisting of the panda from Endangered to Vulnerable, it is clear that society's investment has started to pay off in terms of panda population recovery [13, 14]. Here, we estimate the value of ecosystem services of the panda and its reserves at between $US 2.6 and 6.9 billion/year in 2010. Protecting the panda as an umbrella species and the habitat that supports it yields roughly 10 – 27 times the cost of maintaining the current reserves, potentially further motivating expansion of the reserves and other investments in natural capital in China.

RESULTS AND DISCUSSION

We mapped land use and giant panda (*Ailuropoda melanoleuca*) populations based on data available from four large-scale national surveys from 1980, 1990, 2000, and 2010. We found that a 69.6% decrease in panda habitat (1980-1990) was associated with a 54.8% reduction in panda population size (Table 1; Figure 1). After the China's *National Conservation Project for the Giant Panda and its Habitat* (NCPGPH) was implemented, panda habitat increased (105.4%) from 1990 to 2010, although estimates using remote sensing at higher resolution indicate that recent increases in habitat are more modest and that habitat fragmentation remains a problem [15]. More panda reserves were established and the reserve area increased 3.5-fold from 1980 to 2010. By 2010, a total of 67 panda reserves with an area of 33,118 Km^2 had been established, covering 54.7% (13,852 Km^2) of suitable panda habitat (Table 1; Figure 2).

Giant panda reserves offer a variety of ecosystem services that are valued by local people as well as by the nation. Using reserves to grow crops, graze animals, procure water supplies, and harvest firewood and useful plants are examples of provisioning services. Important regulatory services of forested ecosystems include hydrologic benefits of managing the volume and variability of precipitated water runoff, sediment retention, carbon sequestration, and nutrient retention (Tables S1 and S2). The cultural value of pandas benefits local, national, and international human populations (Tables S3-S8). Economic measures of value are designed to reflect the "net" value of a service to society, not to reflect spending or revenues, tax or otherwise.

We explore the values of pandas and their reserves by reviewing the regulating, provisioning and cultural service values, and collate estimates of the value of these services from numerous studies, converting all estimates to $US, 2010 (see STAR Methods). We used the median value of each service to generate a combined estimate of the annual per-hectare value of all the provisioning and regulating services associated with panda reserves and arrived at a median estimate of $US 632/ha/yr (Table 1 and S2). We multiplied that value by our estimates of forests contained within reserves to estimate the total value of provisioning and regulating services generated by the panda reserves at various points in time. This is conceptually equivalent to estimating real GDP using constant prices. These values increased from $US 562 million per year in 1980 to $US 1,899 million per year in 2010 (Table 1). The 'benefit transfer' approach we use assumes that each hectare of forest produces the same range and quality of ecosystem services. While this simplifying assumption is obviously not the case, it allows a rapid assessment of the value of ecosystem services within the resource constraints, and sets the stage for more detailed, spatially explicit assessments. For a number of reasons, it must be considered a conservative "first cut" estimate (see STAR Methods).

Cultural services include values to people who directly use the resource itself, such as recreational users and governments for ambassadorial or trade purposes. Cultural services also include non-use values, such as bequest and option values for potential future uses. Other cultural services include values to people for the use of images or likenesses of the resources, such as commercial products (toys and backpacks), photographs, cartoons, brand trademarks and logos. In the case of the giant panda, cultural values are expected to be high, as it is an "iconic" species worldwide.

The image of the panda has been incorporated into the logos of a number of conservation NGOs, thereby supporting fund-raising efforts for a variety of conservation programs. The panda brand is frequently used to sell products from toasters to jewelry. Panda-themed restaurants (Panda Express), movies (Kung Fu Panda), and video games (World of Warcraft has a popular panda-themed game) probably generate additional revenues by borrowing the panda's image, though again we cannot be sure what proportion of the revenue is attributed to the panda image. If the panda image were a registered trademark, such as Mickey Mouse, it is likely that these merchandise sales could easily generate enough funds to support the entire panda conservation program in China. Additionally, the above awareness is likely to have contributed to more conservation-focused media outputs, such as recent popular films (eg Disney's Born in China) and TV documentary series (BBC's Wild China).

Zoo-held pandas are almost inevitably the centerpiece of zoological collections exhibiting them and they help drive zoo visits that produce revenues through gate and merchandise sales. For example, long lines outside panda exhibits typify the experience at zoos like the San Diego Zoo, helping to make it the top-ranked zoo attraction in the world**.** The willingness of zoos to pay the Chinese government $1 million annually for the lease of a pair of pandas for ten years is a strong statement of the value of pandas to zoos, and much of the revenues generated from zoo loans is used to implement conservation measures, typically in the reserve system. The U.S. Fish & Wildlife Services requires 80% of these monies to be spent on *in situ* panda conservation, and have established a system of verification. In China, Tripadvisor® voters ranked panda breeding centers as the first or second best tourist attraction in many Chinese towns and cities that have pandas on exhibit. Additional revenues for communities around zoos and panda breeding facilities have not been quantified. Similarly, pandas make an unknown contribution to tourists' motivation to visit nature reserves that contain pandas. Reserves often advertise the presence of pandas even though the opportunities to view them in the wild are extremely limited. However, our analysis does not assume that pandas themselves drive tourism, only that panda protection was a primary factor in establishing the reserve, resulting in other collateral recreational and economic benefits for people. Such multi-use reserves can of course be problematic for the conservation objectives motivating reserve establishment, as tourism can have negative impacts on natural resources and protected wildlife. In some panda reserves, tourism has created demand for recreational horse rides, and increasing populations of horses and other livestock have negative impacts on pandas [16].

We were unable to find studies that valued many of these cultural service values for China, although there were a few that had used willingness to pay surveys of reserve visitors and non-visitors, which we transferred to the panda and its habitat context (see STAR Methods). For this study, we estimated the cultural value based on willingness to pay for panda conservation [17, 18]. From 1980 to 2010, the cultural values of pandas for Chinese residents and their reserves almost doubled (Table 1), largely driven by human population increases. Tourism use-values grew rapidly, rising 500 fold from 1980 to 2010. If the cultural values generated in 2010 were to continue in perpetuity, their net present value (at 3% discount rate) would be $US 23.6 billion (Table S8). Altogether, the total value of the ecosystem services of giant pandas and their reserves increased from $US 0.96 billion/yr in 1980 to $US 2.61 billion/yr in 2010 (Table 1).

Estimating the global value of these cultural services in monetary units is, of course, extremely difficult. We have made an attempt at an approximation, including a number of untested assumptions and extrapolations, but estimate at a general value of approximately $5 billion/yr (see STAR Methods). Since the international community benefits little from local provisioning and regulating (P&R) services, the global value of cultural services appears to far exceed the value of direct P&R services (< $US 2 billion/yr, Table 1). Even in China, the cultural value of pandas and their habitat makes up a significant portion (27%) of the total value. We conclude that the combined value of panda reserves and the panda itself is much greater than just the value of the P&R ecosystem services afforded by the forests.

We estimated the cost for panda conservation in China in the next 20 years under four different scenarios based on changes in reserve area and management effort. The estimated costs of these scenarios ranged from $US 228 to 292 million/yr (Table 2). We compared these costs to the benefits of protecting pandas and their habitats (Benefit/Cost ratio) under different scenarios (Table 2). Our key finding is that the current system (Scenario 1) has a B/C ratio of 10.2 (if we add the cultural value of $5 billion/yr for the global population, it would reach 27.1), implying that the government investment in panda reserves is paying off in terms of ecosystem services. Expanding the reserves and improving management (Scenario 3) could improve this somewhat to 11, but more work needs to be done on the details of how this should happen. A new panda conservation project, the "Giant Panda National Park" (GPNP) has been approved by the central government and would be a good opportunity for testing the validity of these scenarios.

Overall, our study provides a better understanding of the ecosystem service value of giant pandas and their reserves. The Chinese government has invested significant funding in creating and maintaining panda populations and their habitat. The total value of the ecosystem services increased continuously during this period as a result of this investment. In addition, this investment has improved the material living conditions of the local residents. Data from the Chinese Statistical Yearbook shows that the annual income of farmers in provinces adjacent to the panda reserves (Sichuan, Shaanxi, and Gansu) increased by an average of 56% between 2000 and 2010. The annual income of farmers in counties within these provinces adjacent to the panda reserves increased by an average of 64%. Thus proximity to panda reserves produces an 8% better increase in annual farmer incomes relative to the provinces as a whole.

Our analyses indicate that further investment in panda protection can be a beneficial strategy for both people and pandas. With a large proportion of panda habitat still remaining outside the Chinese government's protected area system, an expansion of the reserve system would ensure that the panda will not need to be reclassified as "Endangered" once more [15]. Habitat fragmentation and degradation have been identified as the most critical factors limiting panda recovery, requiring a reserve system that increases connectivity and adequately protects pandas and habitat from increasing disturbance from livestock and other emerging threats [14, 15]. A continuation of existing policies protecting (National Forest Conservation Program) or restoring (Grain to Green Program) forests will also be required to secure the panda's future [14, 15]. Further, existing provincial reserves receive insufficient funding for adequate protection of pandas and natural resources and should be upgraded to national level or better funded. The new "GPNP" will go far to address some of these concerns, and will include most of current panda habitat and connect most of the isolated panda populations and habitats. More pandas and habitat will be protected efficiently, providing more ecosystem service value in the future.

If the relatively massive capital outlay required to put the panda on the path to recovery is warranted in terms of payoff in ecosystem services, perhaps there is a lesson for other species conservation programs. The relatively modest investments by governments and private donors to conserve species may be revised upward and still have significant net benefits for human society, in addition to the intrinsic value of the species and ecosystems themselves. To place this in perspective, the global annual cost to reducing the extinction risk of *all* species is estimated to be less than $5 billion [19], a value less than our estimate for the cultural value of the panda alone. China has already successfully invested significant resources in natural capital restoration [20]. To leverage funds necessary to recover species and protect habitat, estimates of cultural and provisioning services such as ours may prove useful.

SUPPLEMENTAL INFORMATION

Supplemental Information includes eight tables and can be found with this article online.

ACKNOWLEDGMENTS

This work was funded by Ministry of Science and Technology (2016YFC0503200), Chinese Academy of Sciences (XDPB0202, QYZDY-SSW-SMC019), Sichuan Forest Department and State Forestry Administration.

AUTHOR CONTRIBUTIONS

F.W.W. and R.C. led the project with support from all authors; F.W.W., R.C., N.S., Q.D., S.F., Y.G.N., I.K., Y.B.H. and R.R.S. wrote the paper with contributions from all authors.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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Figure Legends

Figure 1. Giant panda habitat in six mountain ranges [QL (Qinling) Mountains, MS (Minshan) Mountains, QLS (Qionglaishan) Mountains, LS (Liangshan) Mountains, DXL (Daxiangling) Mountains, and XXL (Xiaoxiangling) Mountains] and four decades (1980, 1990, 2000 and 2010).

Figure 2. Giant panda reserves established before 1980 (green), during 1981-1990 (yellow), 1991-2000 (orange) and 2001-2010 (brown).

Table 1. Value of ecosystem services from giant panda reserves in different decades

Years[1]	**1980**	**1990**	**2000**	**2010**
Panda population size	2,459	1,112	1,596	1,864
Panda habitat area (Km^2)	40,599	12,340	22,044	25,349
Panda reserve areas (Km^2)	9,347	10,028	22,267	33,118
Forest area within reserves (ha)	890,206	957,086	2,002,656	3,006,349
Value of regulating & provisioning services provided by forests within panda reserves (millions $US, based on $631.63/ha/yr)	$562	$605	$1,265	$1,899
Value of cultural services (millions $US/yr)	$401	$294	$499	$709[2]
Total flow value (millions $US/yr)	$963	$899	$1,764	$2,608[3]

[1]1980, 1990, 2000, and 2010 represent the first, second, third and fourth national survey of giant pandas.

[2]This is for the Chinese population and OECD tourists visiting China. We estimate roughly US$5 billion/yr for the global population (Supplemental Information).

[3]If we include the global cultural value of pandas (excluding the double-counting of US$709 million/yr), this total value can be increased to US$6.9 billion/yr.

See also Tables S1-S8.

Table 2. Costs and benefits of the giant panda protection for different scenarios (from 2011-2030)

Scenario	Habitat area invested (million hectares)	Costs in conservation (US$, million)	Number of personnel	Costs in personnel (US$, million)	Total costs in the next 20 years (US$, million)	Total costs/yr (US$, million/yr)	Total benefits/yr (US$, million/yr)	Benefit/ Cost ratio
Scenario 1: Maintain management of current habitat	2.58	4,628	3,093	476	5,104	255	2,608[1]	10.2
Scenario 2: Improve management of current habitat by 15% through ideal personnel allocation	2.58	4,628	5,160	794	5,422	271	2,893[2]	10.7
Scenario 3: Enlarge the habitat area by 15% through expanding reserves and improve management by 15%	2.967	4,993	5,940	856	5,849	292	3,220[3]	11.0
Scenario 4: Habitat degradation by 20% due to economic slowdown, decreasing in conservation	2.064	4,142	2,473	426	4,568	228	1,924[4]	8.4

investment, personnel and collective forest

[1]Assuming stable human population and total benefits unchanged from 2010. If we use the global value of US$6.9 billion/yr, the Benefit/Cost ratio would be 27.1.

[2]Assuming unchanged cultural services and a 15% increase in provisioning and regulating services due to improved management.

[3]Assuming unchanged cultural services, an increase of forest area by 15% to 3.457 million ha by expanding the reserves and a 15% increase in provisioning and regulating services due to improved management.

[4]Assuming unchanged cultural services and a decrease of forest area in panda reserves by 20% to 2.405 million ha and a 20% decrease in provisioning and regulating services due to habitat degradation.

STAR METHODS

KEY RESOURCES TABLE

CONTACT FOR REAGENT AND RESOURCE SHARING

Requests for further information should be directed to and will be fulfilled by the Lead Contact, Fuwen Wei (weifw@ioz.ac.cn).

METHOD DETAILS

Land Use Mapping

The historical land-use and land-cover data were obtained from the Resource and Environment Data Cloud Platform (www.resdc.cn) supported by the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences. These data were then revised by the dataset of First and Second National Forest Inventory, and the First, Second, Third and Fourth National Giant Panda Survey. The historical habitat ranges were obtained from the above four national giant panda surveys too. The types of land-use and land-cover were pooled into six categories, i.e. forest, grassland, water body, farmland, building area and other types. Area of each category was computed using a projection of Albers equal area conic with central meridian of 105°.

Ecosystem Service Estimation

Ecosystem Service Composition

China's giant panda reserves provide a variety of ecosystem services to many people; local people immediately adjacent to the reserves, larger regions that incorporate these reserves, China at large, and the rest of the world. Using the Common International Classification of Ecosystem Services (CICES) [21], these services include:

(1) Provisioning Services (providing food, water, timber, fuel, fiber, medicinal resources etc.)

(2) Regulatory & Maintenance Services (regulating water flows, natural hazards, soil erosion and fertility, waste treatment, climate, disease, carbon sequestration, nutrient cycling, biodiversity, habitats etc.)

(3) Cultural Services (providing benefits to humans through direct interaction – e.g. recreation and tourism, aesthetics – and also without interaction, as when benefits are provided that are associated with arts and folklore, spiritual values, bequest and existence values)

We attempt to ascertain the economic value of the supply of ecosystem services. By "economic value" we do not imply that these are values from the sale and purchase of these services through markets. In fact, most of these services are not transacted through markets. By "economic value" we mean the worth of these services to people, in the sense of the degree to which they enhance people's well-being. A substantive body of literature focuses on techniques for estimating those 'values', most frequently in monetary terms. Not all techniques are suitable for estimating all ecosystem services, so it is common to find that different types of ecosystem services are estimated in monetary units using different valuation methods (for applied examples of several see: change in the value of output [22]; preventative expenditures [23]; replacement cost [24]; hedonic pricing [25]; travel cost and contingent behavior [26]; acceptance of compensation [27]; choice modeling [28]).

D'Amato *et al*. [29] reviewed the English literature that considered ecosystem service values in Chinese forests, finding 12 studies that collectively provide 72 separate 'value' estimates. Not all of these studies generated new data (instead, transferring values from other studies), and some generated value estimates which were difficult to clearly classify into one service or another, but D'Amato's review [29] highlights significant gaps in the literature. For example: more than 75% of studies considered regulating and maintenance services (almost all generating estimates of the value of services associated with hydrology and climate); about a third considered values associated with tourism; only one discussed aesthetic values.

We build upon D'Amato *et al*.'s paper [29], which focused primarily on studies that generated estimates of the regulating and maintenance services associated with China's forests. We add additional estimates from the literature relating to other ecosystem service values (Table S1) and use the compilation of estimates to draw inferences about the value of different types of services in the Panda Reserves/Habitat. For services that relate to the size of a forest/reserve (the provisioning and regulating/maintenance services) we identify a 'most plausible' estimate of annual value per hectare; generally the median when several estimates are available (thus controlling for outliers). The values of cultural services are not a function of forest/reserve area; rather they depend upon populations (resident or tourist). So for these values, we identify a 'most plausible' estimate of value, expressed in per-household terms. Whenever unable to identify previous literature that has generated value estimates for a particular ecosystem service, we have used an extremely conservative value of '0' instead. As such, our collective estimates of all values (based on total area of reserve/habitat, and particular populations at a given point in time) are almost certainly conservative. Unless otherwise specified, all values are expressed in US$ 2010. As per D'Amato *et al*. [29], if estimates were expressed in Chinese Yuan (RMB), we converted values to 2010 US$ = (RMB value × (PPP_{2010}/PPP_t))/PPP_{2010}, if estimates were expressed in US$, we converted values to 2010 US$ = US value × ($USGDPdeflator_{2010}/USGDPdeflator_t$), where: PPP_{2010} is purchasing power parity for the year 2010 and PPP_t is purchasing power parity for the year of publication (or year in which estimates were generated, if specified in the publication); $GDPdeflator_{2010}$ is the GDP deflator in 2010 and $GDPdefllator_t$ is the GDP deflator for the year of publication (or year in which estimates were generated).

The discounted present values were also calculated for our 'base' year (2010, the year for which most data were available). A survey by the Asian Development Bank noted that

China's National Development and Reform Commission has used a discount rate of 8% for public development projects (p. 32) [30]. The survey also noted that the World Bank used a range of discount rates, 10-12%, in evaluating projects in developing countries (p. 66) [30]. Kubiszewski *et al*. [31] suggested using a range of discount rates given the unsettled controversies surrounding appropriate rates and discounting methods. Rates of 1% and 3% were used in their study in order to account for uncertainties of proper rates, and to reflect the difference between discounting natural system services versus physical capital development projects. We use 3% and 8% in this study, and simply assume the panda values will be constant over an infinite time horizon in contrast to physical projects that are likely to depreciate over time.

Provisioning Services of Panda Forested Habitat

The giant panda reserves offer a variety of items that are valued by local people as well as larger economic areas. Using the reserves to grow crops, graze animals, procure water supplies, and harvest firewood and useful plants are examples of these provisioning services. Relevant empirical estimates (briefly discussed below) are provided in the top part of Table S1.

Several studies have considered the importance of fuelwood in panda reserves. These studies have, primarily, sought to determine the extent to which electricity prices must fall, to entice people to cease collecting fuelwood from the forests [32-35]. This is a measure of the electricity costs which people are able to avoid by using firewood is thus a measure of the value of that firewood, but there was not enough information provided in these papers to generate an aggregate estimate of the value of firewood collected in reserves. Li *et al*. [35] also reported estimates of the number of livestock in forests, but did not generate estimates of the value of the forage they obtain. Liu *et al*. [36] discussed the importance of traditional medicines collected in forest reserves, but did not estimate their value. Guo *et al*. [37] estimated the market value of stumpage in Xingshan County in Hubei province, reporting that value as an 'aggregate' value of 'timber and other forest products – equivalent to $159.05 per hectare (US $2010). However, it is not clear whether stumpage prices or mill prices were used, or whether gross, commercial, or sustainable volumes were used. Stumpage prices and sustainable volumes are necessary to estimate annual forest timber values. So this estimate is not used in our study.

There have also been numerous studies investigating the 'value' of water that is captured, and purified (for human consumption). It should be noted that this potable water supply service is different from the water storage and regulation services, but studies often estimate such values together, primarily because to estimate either the provisioning, or regulatory values associated with hydrological services, one must first determine how much water is captured. From that, one can determine how much is captured and purified for human consumption. Yao [38] estimated volumes of water captured and purified, but not value estimated. An extremely high value was estimated by Niu *et al*. [39], and was omitted from our analysis. Guo *et al*. [37] estimated the potable water value for a Xingshan County in China with 50% forest cover. They estimated the rainwater stored by the forest using the efficiencies of different types of vegetation, soil and slope to estimate water retention. Using the price of water in the country, this yielded an estimate of potable water supply values to be $11.79/ha. Using surface runoff and water prices, Zhang *et al*. [40] estimated that each hectare of forest in the catchments above Beijing, which are 50% forested, generates $122.62 'worth' of freshwater for human consumption. Xie *et al*. [41] used the ratio of runoff to total rainfall to estimate a value of $112.78. Across all three studies, these estimates give a mean of $82.40/ha/yr ($US2010) and a median of $112.78/ha/yr ($US2010), both of which are used in this study.

Regulatory and Maintenance Services of Panda Forested Habitat

Important regulatory services of forested ecosystems include: hydrologic benefits of managing the volume and variability of precipitated water runoff, sediment retention benefits, carbon sequestration, and nutrient retention.

Each of these services has economic implications, and these economic values can be estimated through a variety of recognized methods. Relevant empirical estimates (briefly discussed below) are provided in the middle section of Table S1. These studies (many of which have been compiled and compared in D'Amato *et al*. [29]) evaluated the biophysical impacts of forests in these locations, and used various methods to evaluate them. We have used this literature to provide illustrative estimates of regulatory services in forested ecosystems. These illustrations may be useful in considering the orders of magnitude of these services, but we have not attempted to determine the comparability of contexts between these studies and the giant panda forest reserves.

Air Purification/Pollution Absorption: Two studies have generated biophysical estimates of the amount of SO_2 that can be absorbed by forests [38, 42]; only the second converted those estimates into numerical values, by determining how much it would cost to remove that quantity of SO_2 using alternative methods, $33.71/ha/yr ($US2010). Xie *et al.* [41] estimated the amount of SO2, NOx and HF absorbed by forests, using the replacement cost technique to value that service at $15.67/ha/yr. Guo *et al.* [37] estimated very high values for air purification ($1679/ha/yr) including the value of negative ion generation, pollutant absorption and dust catching, which we omit from this study. We use the mean and median of Xie *et al.* [41] and Xue and Tisdel [42]: $24.69/ha/yr.

Climate Control via Carbon Sequestration: Several studies have estimated the annual carbon sink service of Chinese forests. Piao *et al*. [43] estimated this to be 0.57 (+/- 0.26) tC/ha/yr during the 1980's and 1990's. Jiang *et al*. [44] estimated this to be 0.86 (+/- 0.25) tC/ha/yr during 1999 to 2008. Fang *et al*. [45] estimated the average during 1999 to 2003 to be 1.18 tC/ha/yr. Pan *et al*. [46] estimated Chinese forest sinks during 2000-2007 to be 1.22

tC/ha/yr. We use the median sink value (1.02 metric ton C/ha/yr) and mean value (0.96 tC/ha/yr) for estimating the carbon sequestration value of the panda forest ecosystem.

The economic value of carbon sequestration in panda ecosystems can be considered in terms of the damages to society if that carbon was not sequestered. The US EPA [47] has estimated the global damages of carbon emissions such as agricultural productivity changes, human health impacts, property damages from increased flood risk, etc. One ton of emissions would have long lasting impacts necessitating the discounting of those future impacts. Using a 3% discount rate, the EPA estimated the discounted social cost of a metric ton of CO_2 emissions. For example, a metric ton of CO_2 emitted in 2015 would have a discounted cost of $41.46 ($US 2010), while a ton emitted in 2020 would have a discounted cost of $48.37 ($US 2010). The EPA study calculated costs for CO_2, while our study uses C. The mass conversion factor is that 3.67t CO_2 contains 1t C. We use the $41.46 per ton CO_2, but convert that to $152.15 per metric ton C. Combining the $152.15/tC with the estimated median 1.02 tC/ha/yr, we estimate the annual areal carbon sequestration value of a Chinese forest to be $155.19/ha/yr ($US 2010). The corresponding mean value (0.96 tC/ha/yr) is $146.15/ha/yr ($US 2010).

Nutrient Cycling: Forest vegetation helps maintain soil nutrients - a service which is valuable to the forest, but which also provide services more directly accruing to people. Several studies have looked at the value of this service – assessing how much it would cost to purchase a similar quantity of artificially manufactured nutrients (fertiliser). For example, Xie *et al*. [41] estimated these values (avoided costs) at between $7.06 and $117.66/ha. Xue and Tisdel [42] and Guo *et al*. [37] respectively estimated these values at $95.92 and $523.89/ha. We use the mean, $186.13/ha/yr, and median, $106.79/ha/yr ($US 2010), in this study.

Water Capture and Run-off Regulation: As noted earlier the hydrological processes related to forests help capture/retain water and thus regulate run-off and water flows. Simplistically, this generates several related services that enhance human well-being.

(1) Forests help reduce sediment in water. Forests control sediment runoff through the root networks, reduced water flow, and reductions in the impacts of rainfall on forest surfaces. The values of these services include reduced sediment removal costs in downstream water control structures and consumable water supplies (considered above, as a provisioning service). Only one study, Guo *et al*. [37] specifically estimated water reservoir sediment cost removal savings as $165.45/ha ($US 2010). Several studies evaluated the sediment control services by the costs avoided by not having to use artificial means of sediment removal. Guo *et al*. [37] estimated this savings to be $256.22/ha. Guo *et al*. [48] and Xie *et al.* [41] estimated these savings at $1222.41 and $1.51/ha, respectively. We use the mean, $411.40/ha/yr ($US 2010) and median, $210.84/ha/yr ($US 2010) as estimates in this study.

(2) Forests help reduce soil erosion, by 'slowing' water flows. When fertile soils are eroded, agricultural productivity is affected. We could find only one study (Guo *et al.* [37]) that compared erosion rates in forested and non-forested areas to determine, on average, the extent to which forests reduce erosion, maintain top-soil and thus prevent tracts of agricultural land from becoming 'dis-used'. They estimated the cost of replacing the agricultural top soil lost due to increased erosion. They estimated that each hectare of forest thus creates (protects) $9.66 ($US 2010) cost savings to agricultural production downstream. This value is used in our study.

(3) Forests help retain/store water thus reducing the total volume of run-off and providing flood protection. In principal, these values should be estimated by comparing flood-damages in areas with, and without, forests up stream – the difference representing the damages avoided because of the forest. There are examples of such studies in other ecosystems and contexts (see, for example, Costanza *et al*. [49] who estimated the value of coastal wetlands for hurricane protection). We could not find any such examples for forests in China – although numerous researchers have instead estimated how much it would cost to build man-made storages that would be able to reduce run-off by as much as forests are able to. When

doing this, researchers generally use hydrological models to generate estimates of the amount of water captured by forests; the economic value of the retention service is then usually estimated using either the price of water, or the cost of storing water in man-made reservoirs. It should be noted that such an avoidance cost is a one-time capital expense, not an annual cost. Such capital expenses must be annualized for purposes of this study. Zhang *et al*. [40] estimated that each hectare of forest in the catchments above Beijing generate values associated with water storage costs (avoided) and rainfall interception of $1077.32 per hectare. Peng *et al*. [50] estimated the difference between runoff from vegetated and non-vegetated forests, deriving a water storage avoided cost of $131.29/ha. Li *et al*. [51] based avoided storage costs on the precipitation intercepted by forest canopy, litter and soil, deriving a value of $91.45/ha. Xie *et al*. [41] based their water storage costs avoided on rainfall intercepted compared to rainfall, deriving an estimated value of $923.08/ha. Xue and Tisdel [42] used the difference between precipitation and evapotranspiration to obtain an avoided cost estimate of $345.15/ha. Guo *et al*. [48] also used the precipitation and evapotranspiration difference to estimate an avoided cost of $5064.27/ha. This value is extremely high compared to the others and we exclude it from our analysis. Consequently, the mean and median values are $513.66/ha ($US 2010) and $345.15/ha ($US 2010), respectively. However, these capitalized values must be amortized to annual values. Using a 3% interest rate for amortization results in annualized mean and median values of $15.41/ha/yr and $10.35/ha/yr ($US 2010), respectively, which are used in our analysis.

(4) Forests help improve water quality – essentially a supporting service, the benefits of which are manifested in numerous other ways relating to services already counted in the other values discussed. As noted above, forests provide (potable) water for human consumption (assessed above, as a ‘provisioning’ service). Recreational experiences are also generally enhanced by improved water quality, either directly (e.g increased aesthetic values associated with clear water) or indirectly (e.g. increased aesthetic experiences associated with

more diverse and healthy ecosystems) – so these benefits are manifested through enhanced cultural services.

Pest and Disease Control: Xue and Tisdel [42] generated estimates of the 'value' of pest and disease control services, determining how much it would cost to control pests and diseases using chemicals (approx. $1.33 per hectare per annum (US$ 2010).

Stream Temperature Regulation: We could not find studies that had sought to estimate the value of the service of stream temperature regulation for purposes of downstream consumption is missing from these estimates. An example of a well-done study of this type is Honey-Roses *et al*. [52]. They estimated the reduction in water treatment costs, using the Stream Network Temperature Model (SNTEMP) to determine the reduced need for expensive equipment at water treatment facilities along the Llobregat River in Spain. They estimated stream temperature ecosystem services of existing riparian forest cover to be 79,000 Euros per year. Stream temperature regulation would also impact provisional and recreational (fishing) services.

Summary of Provisioning and Regulating Services

Table S1 lists key provisioning services likely to be associated with panda reserves, research relevant to those services, and the per-hectare value estimates we have used in this study. Our aggregate estimates of the 2010 economic values of provisioning and regulatory (P&R) services of panda habitats are shown in Table S2. We have used mean and median values per ha per annum from the relevant studies we found. For example, column 1 of Table S2 shows a mean value of potable water available from panda habitats to be $82.40 ($US 2010) per ha per annum, while column 2 shows the median value of this service to be $112.78 per ha per annum. The total value of P&R services, for those we could value, has a mean value of $877.17 per ha per annum and a median value of $631.63. Using first, mean values, the last row of Table S2 shows the estimated total annual value of P&R services over the entire 3,006,349 ha of forested panda reserves to be $2.637 billion per annum. Median values show a total reserve P&R value of $1.899 billion per annum. Table S2 also shows the capitalized values of P&R services using discount rates relevant to Chinese investments, 3% to 8%. For example, column 3 shows mean discounted values using a 3% discount rate. Columns 3 through 6 show a range of these mean and median discounted values from $7,895.40 to $29,239.00 per ha, depending on the discount rate used. The last row shows the total discounted values of all panda reserves to range from $23.736 billion to $87.902 billion depending on the discount rate and whether the mean or median values are used.

Cultural Services

Cultural services include values to people who directly use the resource itself, such as recreationists, sport hunters, and governments for ambassadorial or trade purposes. Cultural services also include non-use values, such as bequest and option values for potential future uses. These could be also considered use values, but it makes no difference. Other cultural service include values to people for the use of images or likenesses of the resources, such as commercial products (stuffed toys, backpacks, candy, etc.), photographs, cartoons, brand trademarks and logos, etc. In the case of the giant panda, cultural values are expected to be very high, as it is an "iconic" species worldwide.

Some of these economic values can be estimated through a variety of well-recognized methods, although all methods struggle to monetize some of the more intangible values. Relevant empirical estimates are discussed below.

Use (research) Values: If wishing to correctly assess research values, one would need to determine the benefit, to society, of research undertaken, and subtract from that benefit, the cost of undertaking the research. We could find no empirical studies that had sought to monetize the benefits of panda or panda-reserve related research – such benefits are likely incalculable. Expenditure on research is a poor proxy, since we do not know the relationship between expenditure (essentially the cost of undertaking the research) and benefits. If benefits are equal to (greater than, less than) expenditure, the net benefit of research will be equal to (greater than, less than) zero. Whilst anecdotal evidence suggests the research values are likely extremely high, we have nevertheless taken a relatively conservative stance by assessing net benefits at zero.

Use (tourism and recreation) Values: Swanson and Kontoleon [10] and Li *et al*. [35] estimated regional expenditures per visitor. But these estimates relate to the regional economic impact/importance of pandas, rather than to the value of ecosystem services (technically, the value of such a service is the difference between the most people would pay, and the costs actually paid, the latter being expenditures). Swanson and Kontoleon [10] used a CV to assess visitor WTP for improved tourist facilities in and around reserves – but do not explicitly link the assessment to Pandas or Panda reserves, so we are unable to use those estimates here.

Zong *et al*. [17] surveyed visitors to the Wolong reserve to determine the willingness to pay (WTP) for the existence of the panda at the Wolong reserve. This value was $27.68 per visitor household to the Wolong reserve per annum. This value could be interpreted as the WTP to avoid the total loss of all pandas at Wolong by reserve visitors, so is probably a combination of use and non-use ('existence') values. Although this study was only undertaken in the Wolong reserve, in the absence of other information we have used it as an estimate of the use and non-use values of those who visited reserves during 2010 (just two years after the study was published). Total values are estimated by multiplying the per visitor household value of $27.68 by the number of visitors, and dividing through by average household size.

Richardson and Loomis [18] provided a compilation of nearly 50 studies of *use and non-use* values considering people's WTP for iconic or key-stones species. They used data from those studies within a regression analysis to establish the following 'benefit transfer' equation:

ln Willingness to Pay ($2006)= -153.231 + 0.870 ln CHANGESIZE + 1.256 VISITOR

+ 1.020 FISH + 0.772 MARINE + 0.826 BIRD - 0.603 ln RESPONSERATE

+ 2.767 CONJOINT + 1.024 CHARISMATIC - 0.903 MAIL + 0.078 STUDYYEAR

where:

ln Willingness to Pay: natural log of the annual WTP values per US visitor or non-visitor household, whichever is appropriate, in $US 2006.

ln CHANGESIZE: natural log of the change in size from the current population, in percentages

VISITOR: whether the respondent was a visitor to the species (e.g., wildlife or marine refuge) (VISITOR=1) or a non-visiting household (VISITOR=0)

FISH: whether the valued species was a fish (FISH=1), otherwise FISH=0

MARINE: whether the valued species was a marine animal (MARINE=1), otherwise MARINE=0

BIRD: whether the valued species was a bird (BIRD=1), otherwise BIRD=0

(NOTE: mammals were the omitted species category, to avoid the dummy variable trap; i.e., for mammals, FISH=MARINE=BIRD=0)

ln RESPONSERATE: the survey response rate, in percentages

CONJOINT: whether the survey used a conjoint elicitation procedure (CONJOINT=1), otherwise CONJOINT=0 (NOTE: there are several types of WTP survey procedures, conjoint analysis being one of them)

CHARISMATIC: whether the species was considered a “charismatic” one, such as the whooping crane or sea otter (CHARISMATIC=1), otherwise CHARISMATIC=0

MAIL: whether the survey was a mail survey (MAIL=1) or an in-personal or phone interview (MAIL=0)

STUDYYEAR: the year in which the study was done, e.g., 1995

We used coefficients from this equation to estimate the WTP by visitors to reserves for the 2010 population of pandas (i.e. for 0% change) (the values assigned to other coefficients were: VISITOR=1 to signify a visitor (hence 'use value'), FISH=MARINE=BIRD=0, CHARISMATIC=1; CONJOINT=0, MAIL=0; and RESPONSERATE=50). These estimates were adjusted to allow for the fact that the Richardson and Loomis's study [18] was based upon respondents in the US. We assume that Chinese households hold the same values relative to their income as US households for endangered and rare species. Median US household annual income in 2014 was $53,657 (Statista), while the median Chinese household annual income in 2014 was 29,361 yuan (Statista). Using the World Bank's PPP for 2014 (requires 3.77 yuan to purchase the same quantity of goods and services), this would imply a median Chinese household annual income in 2014 of $7782.58, 14.5% of US incomes, so we multiply WTP estimates from the Richardson and Loomis benefit-transfer equation by 0.145 to generate estimates of Chinese user WTP. For the year 2010, the use-value estimates, inferred from that study, were $34.35 for US visitors, and $4.98 for Chinese visitors. Recognising that most visitors to Panda Reserves are Chinese nationals, we use only the Zong *et al.* [17] and the (inferred) Richardson and Loomis [18] WTP estimates for Chinese nationals, to estimate mean and median panda-use values during 2010 ($16.33) per household per year.

We use additional information from the Richardson and Loomis study to infer per-visitor household values at various points in time, each with different populations of the Giant Panda – essentially adjusting the $16.33 estimate upwards or downwards, for different years, and populations (Table S3): WTP per annum per household during 2000, 1990 and 1980 respectively is $14.16, $10.34 and $20.48. We then multiply per-visitor-household values by estimates of the number of visitor-households in each year, to generate estimates of total use-values, for relevant years (Table S4).

Non-Use (Bequest, Existence and Option) Values: Kontoleon and Swanson [53] interviewed tourists to China who were residents of OECD countries. Respondents were informed that 500 was a Minimum Viable Population for the Wolong reserve, and they were then asked their WTP for population increases from 200 to 500. Most likely, respondents would have considered this a payment for the assurance of "saving the panda" which is more significant than just the 300 population increase. The respondents claimed they would be willing to pay an airport tax surcharge upon leaving China of $5.01, $10.82 and $19.07 (US$ 2010) per person to increase a captive panda population from 200 to 500 in cages of 100 sq meters; pens of 5000 sq meters (roughly one-half hectare) and in natural reserves with 400 hectares per panda. It was made clear to respondents that panda conservation entailed no recreational benefits since ecotourism is not possible in the treacherous mountains of Sichuan, so these estimates are best interpreted as representing a WTP for "saving the panda", capturing existence and bequest values, and perhaps also some option values (some of which might be associated with keeping open the option of visiting pandas in the future). Research suggests that 'scope' sensitivity can be a problem in CV studies (e.g. people may be WTP considerable amounts to save the first animal, much less subsequently) [54]. So we have deliberately chosen the lowest estimate as a proxy for OECD non-use values, at $5.01 per visiting household per year (with an estimated 12.26 million OECD visitors, or 4.85 million household-visitors, to China during 2010).

We could not find a study that provided non-use values for Chinese residents. As noted above, Richardson and Loomis [18] provide a compilation of nearly 50 studies considering people's WTP for iconic or key-stones species. Using an approach similar to that used for visitors when inferring 'use-values', we were able to use coefficients from that study to infer that, for the samples considered in the Richardson and Loomis study, non-users would be willing to pay $9.78 per household per annum. Chinese non-users (Visitor=0 in their equation) can thus be assumed to be willing to pay 14.5% of that, or $1.42 per household per annum for existing panda population ($US 2010). The inferred WTP (per Chinese household per annum) for the populations in 2000, 1990 and 1980 were, respectively, $1.23, $0.90 and $1.78 (Table S5).

We note that it is possible to infer non-use values for non-Chinese residents at $9.78 per household per annum (from the Richardson and Loomis study). Extrapolating that figure requires assumptions about the relevant 'world' population to include, and is thus highly speculative. If, for example, we divide the estimated 2010 OECD population (1,236,914,000; http://stats.oecd.org/Index.aspx?DatasetCode=POP_FIVE_HIST) by the average OECD family size in that year (2.63; https://www.oecd.org/els/soc/47701118.pdf), then the total number of OECD households is approximately 470 million. Multiplying that by $9.78 gives an aggregate estimate of $4.6 billon; but we have not included this value within our aggregate estimates because the primary aim of our study was to assess values for China (moreover, OECD countries include China, so to add it, would be to double count; we would need to make adjustments for incomes of all). Even if the intent of the study had been to estimate world values, determining what populations should be included is a non-trivial task, and much further work would be required to tailor the Richardson and Loomis estimates for differences in the incomes of relevant populations.

However, it is clear that panda existence values do exist for the non-Chinese population. As a very rough estimate, we assumed the $4.6 billion/yr above for OECD countries and round up to $5 billion/yr to include the non-OECD countries.

Kontoleon and Swanson [53] study also asked for WTP for panda conservation when the probability of success was low. This resulted in a mean WTP of only $0.13 per respondent. This low value illustrates the importance of the panda in establishing value for the conservation of reserves, per se; the value can also be interpreted as representing WTP for conservation of the reserves without panda (i.e. the non-use value of the forests themselves).

We have therefore used \$0.13 (\$US 2010) per OECD visitor as an estimate of the non-use value of the reserves (without pandas).

Hsee and Rottenstreich [54] asked US University of Chicago students what they would be willing to pay to save the endangered pandas if scientists could discover a number of pandas in a remote Asian region. The purpose of this study was mostly of academic interest in the psychology of valuation and not for the purpose of assessing the valuations of pandas. Also, a student population is probably not very representative of a general population. So these estimates have been excluded from our aggregate analysis.

'Rental' Value of Pandas: The Chinese Government has, for some years, received regular income from zoos throughout the world for 'rental' of Pandas. These rents are a manifestation of cultural values (people throughout the world are willing to pay money to visit zoos that have Pandas, and the zoos willingly remit some of the money back to China). To include those remittance on top of the WTP values discussed above would thus be to 'double count' the value of some cultural services.

Trademarks and Commercial Values:

> *A* ***trademark*** *typically protects names, words, slogans and symbols that identify a business or brand and distinguishes it from others.* ***Trademarks*** *include brand names such as "Coca-Cola" and symbols such as Nike's famous "swoosh."* (Legalzoom.com)

Many different animals have been used as trademarks: pandas, jaguars, lions, elephants, tigers, cats, cobras, leopards, etc. This is perfectly legal, and trademarks are properties that have economic value and, when registered can be infringed and when infringed litigated for damages. Trademarks using similar animal images can be distinctive in very subtle ways, such as how the animal is posed and colored.

We are unware of any study that has attempted to estimate these values. It would be very difficult questions to do so without some type of consumer survey, which is beyond the abilities of this study. Similarly for issues associated with the use of panda images for stuffed toys, backpacks and other commercial artefacts. We also acknowledge the significant ambassadorial and trade services associated with the panda, but are unware of any study that has attempted to monetise that value, and suspect its value may be incalculable.

Summary of Cultural Services

Table S6 provides a summary of relevant literature and the 2010 values used in this study (wherever possible, the most conservative estimate has been selected). Table S7 provides summary values for each type of cultural service, for each year in which we had data that allowed us to estimate aggregate values – multiplying per-household estimates of WTP, by corresponding estimates of the total number of households. Table S8 collates the values and presents aggregate estimates of use and non-use values for 2010. The WTP by non-Chinese tourist households for preserving pandas in their natural conditions are also shown in column 1. Column 2 shows the relevant number of households in the three core areas in which Panda reserves are located (Sichuan, Shaanxi and Gansu) and in the rest of China; it also shows the relevant number of OECD tourists to China. Column 3 uses an average of 2.6 OECD persons per household to convert the number of OECD tourists to tourist households. Column 5 shows the calculated total WTP per annum. Columns 6 and 7 show the present (capitalized) values of these annual estimates.

General Ecosystem Services Methodological Issues, Limitations and Caveats

Relevant Literature: Our research procedure was to limit ourselves to English language, peer-reviewed literature. We began by searching relevant journals, such as Ecological Economics and Ecosystem Services, for ecosystem valuation studies of Chinese forests, as well as studies directly related to the economic value of pandas, per se. We then followed up the references cited in these studies, alongside keyword searches. We did not accept studies that did not specify their methodologies clearly or did not use appropriate methods, or did not define clearly the ecosystem services valued. Although there were white paper studies that first appeared relevant, upon further investigation we found them unsatisfactory in terms of rigor, clarity and specificity; so we did not include their results. The authors include a large number of specialized Chinese scientists who, among them, are familiar with all relevant studies of giant pandas and Chinese forests. They provided us with relevant studies we missed in our literature searches. However, our literature searches already were quite thorough, as the Chinese scientists found rather few studies of which we were unaware.

Double Counting: There were three potential double counting issues with which we were aware, and of which we believe were avoided in our analysis. The first was making certain that we separated the values of pandas, per se, from the non-panda ecosystem services of their habitats. Evidently, one ecosystem service of panda habitat to support the panda, a species with considerable cultural value. But we have separated this from other habitat ecosystem services, such as provisional and regulatory values. The second potential double counting issue arises when considering the hydrologic and sediment related services of forests. Forests provide multiple, joint hydrologic values, but each can be valued separately. For example, rainfall storage and regulation provide benefits of potable water supply as well as management of downstream flooding. These are two separate values, although they are provided jointly by the forest. Another joint service is sediment retention, which enhances soil structure for forest growth and sustainability. But it also reduces the maintenance costs of downstream flood control and water storage structures. Enhanced forest soil fertility and reduced downstream maintenance costs are separable values with a joint benefit. A third possible double counting could arise when considering cultural values. When soliciting willingness to pay values for panda preservation it is possible that respondents have more in mind than just the panda. They may be including the values of the ecosystems in which pandas reside; thus possibly incorporating other ecosystem service values (provisioning and regulatory) in their responses. We believe this is unlikely, as willingness to pay studies were very explicitly focused on the panda itself; and consideration of other habitat values would be quite tangential (or unknown) to respondents. We were also aware of the potential for double counting in the use of other researchers' studies, and ensured that our use of their data did not pose any serious double counting problems for our study.

Limitations of Methods (Physiological and Other): There are many articles discussing the strengths and limitations of the methods used in the studies we have selected to include for benefit transfer. That there are so many books and articles of this nature reflects the fact that a) there are many different methods, none of which are and none of which can be used in all situations; and b) there is a long history of valuation from which various methods (and critiques) have been developed [55-58]. Perhaps the greatest limitation of methods used is that we included studies of forest ecosystems that were not panda habitats, per se. Obviously, forests differ in terms of their biological and geophysical structure, as well as their proximity to human populations, all of which could determine the economic values of their ecosystem services, such as water supply and flood protection services. The types of trees, vegetation, age, etc. of a forest would affect carbon sequestration services. But there were not enough relevant studies of forest ecoservices to allow us to perform a statistically adjusted benefits transfer.

Costs Estimation

The costs in panda conservation mainly consist of two parts: the direct costs such as the habitat conservation and reserve infrastructure construction, and the indirect costs for reserve personnel. We estimated both costs based on data from the 4th National Survey of Giant Panda in Sichuan. The habitat conservation of 2.0272 million hectares in Sichuan cost 11.821 billion RMB in the past ten years with an average of 583 RMB per hectare per year. Based on this price unit, we estimated the direct costs needed for panda conservation in China in the next 20 years (2011-2030) for the whole habitat (2.58 million hectares). In addition, yearly cost of reserve staff in Sichuan is estimated to be 50 thousand RMB per staff. Therefore, the total personnel costs for 3,093 on-post staff for panda conservation are estimated to be 154.65

million RMB in 2010. Based on the above direct and indirect costs, we estimated costs in four different scenarios in the next 20 years (2011-2030, Table 2).

QUANTIFICATION AND STATISTICAL ANALYSIS

The calculated methods of ecosystem service values were explained in detail in the METHOD DETAILS section.

DATA AND SOFTWARE AVAILABILITY

The ecosystem service value-related data were detailed and summarized in Tables 1-2 and Table S1-S8. The historical land-use and land-cover data in 1980, 1990, 2000 and 2010 were downloaded from Resource and Environment Data Cloud Platform (www.resdc.cn).

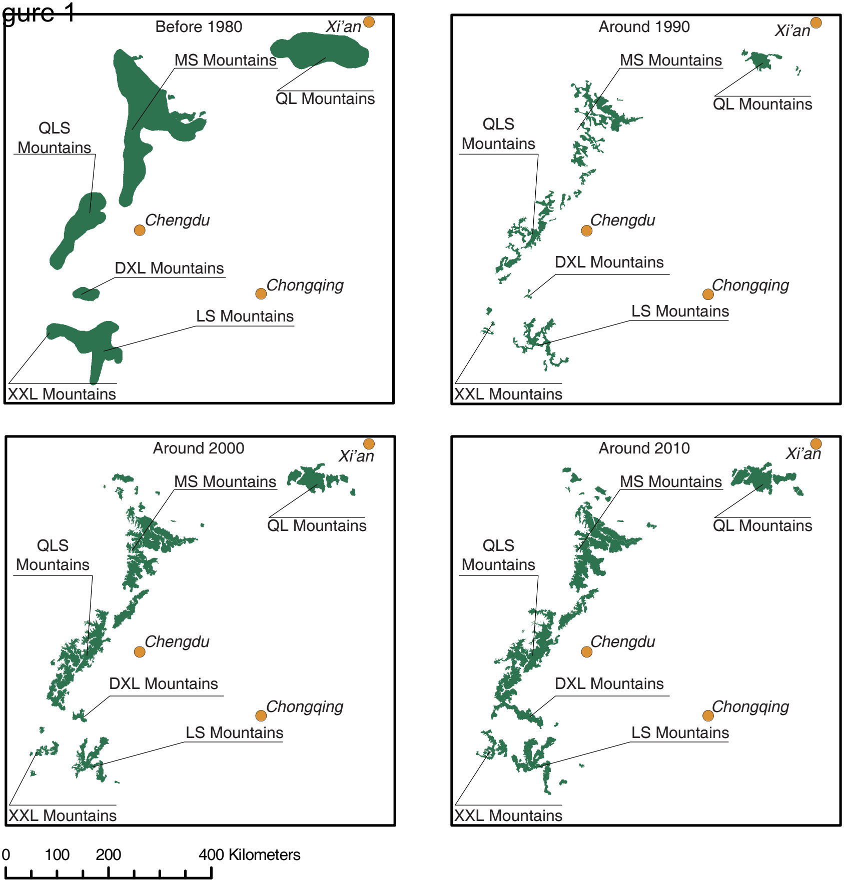
TABLE FOR AUTHOR TO COMPLETE

Please upload the completed table as a separate document. ***Please do not add subheadings to the Key Resources Table.*** *If you wish to make an entry that does not fall into one of the subheadings below, please contact your handling editor. (**NOTE:** For authors publishing in Current Biology, please note that references within the KRT should be in numbered style, rather than Harvard.)*

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Other		
Land-use and land-cover data in 1980	Resource and Environment Data Cloud Platform	http://www.resdc.cn/data.aspx?DATAID=197
Land-use and land-cover data in 1990	Resource and Environment Data Cloud Platform	http://www.resdc.cn/data.aspx?DATAID=95
Land-use and land-cover data in 2000	Resource and Environment Data Cloud Platform	http://www.resdc.cn/data.aspx?DATAID=97
Land-use and land-cover data in 2010	Resource and Environment Data Cloud Platform	http://www.resdc.cn/data.aspx?DATAID=99

Figure 1


Before 1980
Xi'an
MS Mountains
QL Mountains
QLS Mountains
Chengdu
DXL Mountains
Chongqing
LS Mountains
XXL Mountains
Around 1990
Xi'an
MS Mountains
QL Mountains
QLS Mountains
Chengdu
DXL Mountains
Chongqing
LS Mountains
XXL Mountains
Around 2000
Xi'an
MS Mountains
QL Mountains
QLS Mountains
Chengdu
DXL Mountains
Chongqing
LS Mountains
XXL Mountains
Around 2010
Xi'an
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QL Mountains
QLS Mountains
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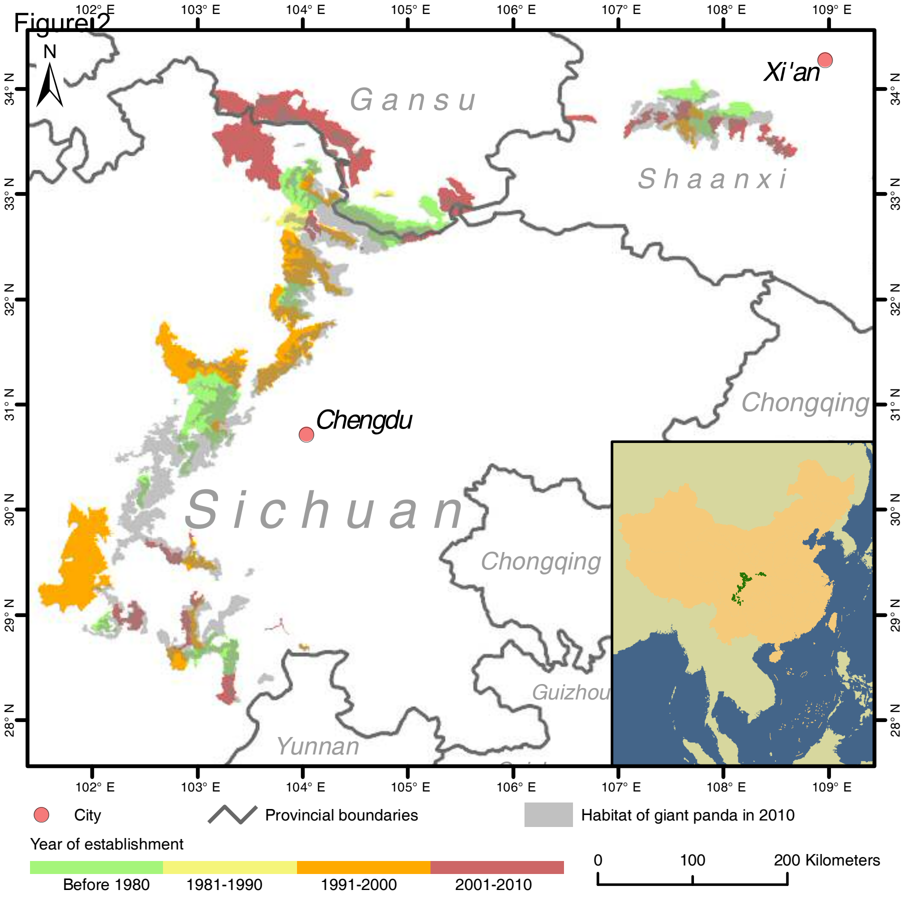
LS Mountains
XXL Mountains
0 100 200 400 Kilometers

Figure 2



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29° N
28° N
Gansu
Shaanxi
Xi'an
Chengdu
Chongqing
Sichuan
Chongqing
Guizhou
Yunnan
City
Provincial boundaries
Habitat of giant panda in 2010
Year of establishment
Before 1980
1981-1990
1991-2000
2001-2010
0
100
200 Kilometers

Division	**Relevant examples**	**Empirical studies relevant to pandas and panda reserves**	**Estimate used in this study (2010 US$)**
Nutrition	Crops	None found	0
	Traditional medicines and bush-meat	Liu *et al.* [S1] discuss but do not estimate value	0
	Potable Water	Yao [S2] estimate volumes of water captured and purified, but not value estimated. Guo *et a*l. [S3], Zhang *et al.* [S4] and Xie *et al.* [S5] generate estimates of $11.79, $122.62 and $112.78 /ha/annum.	$82.40/ha/annum (mean) $112.78 /ha/annum (median).
Materials	Timber and other forest products	Guo *et al.* [S3] estimate values for timber and other forest products at $159.05 per hectare; but there was not enough detail provided in these papers to transfer estimates for use here.	0
	Grazing	Liu *et al.* [S1] present stock numbers but do not estimate value.	0
Energy	Fuelwood	An *et al.* [S6-S8] consider fuelwood, and estimate the change electricity prices required to reduce fuelwood demand, but no aggregate value of fuelwood estimates	0
Mediation of waste, toxics & other nuisances	Air purification/ Pollution absorption	Yao [S2] estimate SO_2 absorption and O_2 creation without values; Xue and Tisdell [S9] use SO_2 absorption x Alternative Cost ($33.69); Xie *et al*. [S5] use replacement cost for removing SO_2, HF and NOx ($15.69)	$24.69 /ha/annum

Division	Relevant examples	Empirical studies relevant to pandas and panda reserves	Estimate used in this study (2010 US$)
Maintenance of physical, chemical, biological conditions	Carbon Sequestration	Piao *et al.* [S10], Jiang *et al.* [S11], Fang *et al.* [S12], Pan *et al.* [S13] estimate the annual carbon sink service of Chinese forests at 0.57, 0.86, 1.18 and 1.22 tC/ha/annum. We use the EPA's estimate of the discounted cost of carbon, at 41.46 per ton, to estimate the mean and median carbon sequestration value of a Chinese forest at $146.15/ha/annum and $155.19 /ha/annum respectively	$146.15/ha/annum (mean) $155.19/ha/annum (median)
	Nutrient Cycling	Xie *et al.* [S5], Xue and Tisdel [S9] and Guo *et al.* [S14] estimate these values at: between $7.04, and $117.66/ha; $95.92/ha; and $523.89/ha – using cost of purchasing fertilizer with similar nutrients.	$186.13/ha/annum (mean) $106.79/ha/annum (median)
	Stream temperature regulation	None found	0
	Control of silt and sediment in waterways	Guo *et al.* [S3] estimate sediment cost removal in reservoirs at $165.45/ha/annum; Avoided costs estimates from Guo *et al.* [S3], Guo *et al.* [S14], and Xie *et al.* [S5] are $256.22/ha/annum, $1222.41 and $1.51/ha/annum	$411.40/ha/annum (mean) $210.84 /ha/annum (median)
	Water retention and flood mitigation	None have determined the potential flood-mitigation value of that storage (the relevant value). Zhang *et al.* [S4], Peng *et al.* [S15], Li *et al.* [S16], Xie *et al.* [S5] and Xue and Tisdel [S9] estimate the cost of retaining a similar amount of water in man-made storages at, $1077.32, $131.29, $91.45, $923.08, and $345.45/ha/annum respectively, these estimates must be capitalized for annualized values (we used 3% discount rate).	$15.41/ha/annum (mean) $10.35/ha/annum (median)

Division	Relevant examples	Empirical studies relevant to pandas and panda reserves	Estimate used in this study (2010 US$)
	Prevention of soil erosion	Guo *et al.* [S3] generate estimates of $9.66 (lost productivity from estimates of prevented soil loss)	$9.66/ha/annum
	Pest and disease control	Xue and Tisdel [S9] (avoided cost of controlling chemically)	$1.33/ha/annum
	Genetic diversity	Substantive body of literature on genetic importance of Panda, but no value estimates	0

Table S1. Provisioning and regulating services associated with the giant panda reserves, Related to Table 1.

Provision and Regulating Service (P&R)	Mean Value per ha per annum ($US2010)	Median Value per ha per annum ($US2010)	Mean Present Value per ha ($US2010) Using 3% discount rate	Mean Present Value per ha ($US2010) Using 8% discount rate	Median Present Value per ha ($US2010) Using 3% discount rate	Median Present Value per ha ($US2010) Using 8% discount rate
Potable Water	82.4	112.78	2,746.67	1,030.00	3759.34	1,409.75
Air Purification	24.69	24.69	823	308.63	823	308.63
Carbon Sequestration	146.15	155.19	4,871.67	1,826.88	5,173.00	1,939.88
Nutrient Cycling	186.13	106.79	6,204.33	2,326.63	3,559.67	1,334.88
Sediment Control	411.4	210.84	13,713.33	5,142.50	7,028	2,635.50
Water Retention	15.41	10.35	513.67	192.63	345	129.38
Prevent Soil Erosion	9.66	9.66	322	120.75	322	120.75
Pest Control	1.33	1.33	44.33	16.63	44.33	16.63
Total P&R per ha	$877.17	$631.63	$29,239.00	$10,964.65	$21,054.34	$7,895.40
Panda Reserve Forest Cover 2010 (hectares)	3,006,349					
Total P&R for entire reserve	$2.637 bil	$1.899 bil	$87.902 bil	$32.964 bil	$63.297 bil	$23.736 bil

Table S2. Summary of provisioning and regulating service values used in this study, Related to Table 1.

Year	Giant panda population	%Change in population from 2010	%Change in WTP if only the year changes = 0.78 * change in years	% Change in WTP if only the number of pandas change = 0.87 * percentage change in pandas	% Change in WTP if both year and population change	Combined effect of year and price change (inferred WTP)
2010	1,864					$ 16.33
2000	1,596	-14.38	-0.78%	-12.51%	-13.29%	$ 14.16
1990	1,112	-40.34	-1.56%	-35.10%	-36.66%	$ 10.34
1980	2,459	31.92	-2.34%	27.77%	25.43%	$ 20.48

Table S3. Drawing inferences about use-values with different giant panda populations (Chinese visitors to panda reserves), Related to Table 1.

Year	1980	1990	2000	2010
Panda Population	2,459	1,112	1,596	1,864
Use values per visitor household to panda reserves	20.48	10.34	14.16	16.33
Wanglang	0	100	4770	3000 * low numbers due to earthquake re-build
Wolong	0	0	64000	0 (road blocked from earthquake)
Jiuzhaigou	2,633	200,000	1,600,000	3,000,000
Huanglong (1983 substituted for 1980)	7,000	120,800	386,541	1,100,000
Panda base				652,706
Total estimated number of visitors to panda reserves	9,633	320,900	2,055,311	4,103,000
Average HH size[1]	4.43	3.5	3.13	2.88
Visitor Households	2,175	92,686	656,649	1,424,653
Total use values of visitors to reserves	$44,534	$948,030	$9,298,148	$23,264,580

Table S4. Use (tourism and recreation) values in 1980-2010, Related to Table 1.

[1]http://www.statista.com/statistics/278697/average-size-of-households-in-china

Year	Panda Population	%Change in population from 2010	%Change in WTP if only the year changes = 0.78 * change in years	% Change in WTP if only the number of pandas change = 0.87 * percentage change in pandas	% Change in WTP if both year and population change	Combined effect of year and price change (inferred WTP)
2010	1,864					$1.42
2000	1,596	-14.38	-0.78%	-12.51%	-13.29%	$1.23
1990	1,112	-40.34	-1.56%	-35.10%	-36.66%	$0.90
1980	2,459	31.92	-2.34%	27.77%	25.43%	$1.78

Table S5. Drawing inferences about non-use-values with different panda populations (Chinese non-visitors), Related to Table 1.

Division	Relevant examples	Empirical studies relevant to Pandas and Panda Reserves	Estimate used in this study for the year 2010 (2010 US$)
Physical and intellectual interactions with ecosystems & land-/seascapes	Tourism	Zong *et al.*'s CV study [S17] found visitors were WTP $27.68 per household per annum; Richardson and Loomis study [S18] suggests that Chinese visitors were WTP $4.98.	$16.33 per Chinese tourist- household per annum during 2010, with panda population of 1864
	Recreation (local residents)	None found	0
	Artistic/aesthetic values	None found; but pandas a common and prominent feature in much traditional and modern art	0
	Research	None found – only expenditure (cost of research) data available, which does not adequately describe benefits net of cost.	0
Spiritual, symbolic & other interactions with ecosystems & land-/seascapes	Existence/Bequest /Option associated with Pandas	Richardson and Loomis's meta-analysis [S18] suggests values of $1.42 per Chinese household per annum for existing populations (associated estimates of $9.78 per non-Chinese household per annum omitted from overall estimates)	$1.42 per Chinese household
		Kontoleon and Swanson [S19] estimate that OECD visitors to China would be WTP between $5.01, $10.82 and $19.07 per household per annum to increase captive panda population from 200-500 in pens of 100sq metres, 0.5 ha, and 400 hectares respectively.	$5.01 per OECD household visiting China per annum

Division	Relevant examples	Empirical studies relevant to Pandas and Panda Reserves	Estimate used in this study for the year 2010 (2010 US$)
	Existence/Bequest/ Option associated with Reserves (without Panda)	Kontoleon and Swanson [S19] estimate that OECD visitors to China would only be WTP $0.13 per household per annum to increase reserves, if there were little chance that this would help increase panda population.	$0.13 per OECD household visiting China per annum
	Trade-marks, Logos, images and commercial values; Ambassadorial and Trade Services	None found	0

Table S6. Cultural Services associated with pandas and panda reserves with estimates used for 2010, Related to Table 1.

	1980 (panda population 2459)	1990 (panda population 1112)	2000 (panda population 1596)	2010 (panda population 1864)
Cultural (recreation) use-value (million USD)				
Value per visitor household	$20.48	$10.34	$14.16	$16.33
Number of visitor households	2,174	91,686	656,649	1,424,653
Aggregate value ($ million, US 2010)	$0.044	$0.948	$9.298	$23.264
Cultural non-use value of Pandas (million USD)				
Value per household	$1.78	$0.90	$1.23	$1.42
Number of households in Sichuan, Gansu and Shaanxi	27,373,454	38,149,374	46,313,099	49,764,178
Number of households in the rest of China	197,705,553	288,507,768	358,607,029	415,829,572
Aggregate value for households in Sichuan, Gansu and Shaanxi	$48.724	$34.334	$56.965	$70.665
Aggregate value for households in the rest of China	$351.916	$259.657	$441.087	$590.478
Cultural non-use value of Pandas for OECD household visitors to China ($5.01 × Household visitors)	No estimates of the number of OECD visitors to China	No estimates of the number of OECD visitors to China	No estimates of the number of OECD visitors to China	$23.624

Cultural non-use value of reserves (without Panda) for OECD visitors to China ($0.13 × Household visitors)	No estimates of the number of OECD visitors to China	No estimates of the number of OECD visitors to China	No estimates of the number of OECD visitors to China	$0.613

Table S7. Aggregate estimates of cultural services associated with pandas and panda reserves in 1980 – 2010 (millions, US$2010), Related to Table 1.

	1	2	3	4	5	6	7
					Value per annum ($ million)	Present Value using 3% discount rate ($ million)	Present Value using 8% discount rate ($ million)
2010 Values (given 2010 reserve size and panda population)							
Panda recreational use-values	$16.33 per Chinese visitor household	4.103 million visitors to *Panda Base, Wanglang, Wolong, Jiuzhaing, and Huanglong nature reserves*	2.88 average persons per household	1.425 million visiting households	23.27	775.67	290.88
Panda non-use value of residents of Sichuan, Gansu and Shaanxi (inferred from Richardson and Loomis [S18])	$1.42 per household	143.320 million people in Sichuan, Gansu and Shaanxi	2.88 average persons per household	49.764 million households in Sichuan, Gansu and Shaanxi	70.67	2,355.67	883.38
Panda non-use value of all other Chinese residents (inferred from Richardson and Loomis [S18])	$1.42 per household	1,198.589 million people in the rest of China	2.88 average persons per household	416.177 million households in the rest of China	590.97	196,99	7,387.13
Panda non-use value for OECD residents: Preserve pandas in natural conditions at Wolong Reserve	$5.01 per OECD visiting household to China per annum	12.260 million OECD tourists visiting China (2010 est)	2.6 OECD persons per household	4.715 million OECD households visit China (2010 est)	23.62	787.33	295.25
Reserve non-use value (preserve reserves with no guarantee of panda survival)	$0.13 per OECD visiting household to China per annum	12.260 million OECD tourists visiting China (2010 est)	2.6 OECD persons per household	4.715 million OECD households visit China (2010 est)	0.61	20.33	7.63
Total cultural values					709.14	23,618	8,864.27

Table S8. Summary of cultural service values in 2010, Related to Table 1.

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