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Contributed Paper

Effects of payments for ecosystem services on wildlife habitat recovery

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Abstract: *Conflicts between local people's livelihoods and conservation have led to many unsuccessful conservation efforts and have stimulated debates on policies that might simultaneously promote sustainable management of protected areas and improve the living conditions of local people. Many government-sponsored payments-for-ecosystem-services (PES) schemes have been implemented around the world. However, few empirical assessments of their effectiveness have been conducted, and even fewer assessments have directly measured their effects on ecosystem services. We conducted an empirical and spatially explicit assessment of the conservation effectiveness of one of the world's largest PES programs through the use of a long-term empirical data set, a satellite-based habitat model, and spatial autoregressive analyses on direct measures of change in an ecosystem service (i.e., the provision of wildlife species habitat). Giant panda* (Ailuropoda melanoleuca) *habitat improved in Wolong Nature Reserve of China after the implementation of the Natural Forest Conservation Program. The improvement was more pronounced in areas monitored by local residents than those monitored by the local government, but only when a higher payment was provided. Our results suggest that the effectiveness of a PES program depends on who receives the payment and on whether the payment provides sufficient incentives. As engagement of local residents has not been incorporated in many conservation strategies elsewhere in China or around the world, our results also suggest that using an incentive-based strategy as a complement to command-and-control, community- and norm-based strategies may help achieve greater conservation effectiveness and provide a potential solution for the park versus people conflict.*

Keywords: forest monitoring, giant panda, habitat recovery, Natural Forest Conservation Program, park–people conflict, spatiotemporal dynamics, Wolong Nature Reserve

Efectos de los Pagos por Servicios Ambientales sobre la Recuperación del Hábitat de la Faun

Resumen: *Los conflictos entre el bienestar de los habitantes locales y la conservación han derivado en numerosos esfuerzos de conservación sin éxito y han estimulado los debates sobre las políticas que pueden simultáneamente promover el manejo sustentable de las áreas protegidas y mejorar las condiciones de vida de los locales. En todo el mundo se han implementado muchas estrategias de pagos por servicios ambientales (PSA) patrocinados por el gobierno. Sin embargo, se han realizado pocas evaluaciones de su efectividad, y muchas menos se han realizado para medir directamente sus efectos sobre los servicios ambientales. Realizamos una evaluación empírica y espacialmente explícita de la efectividad de conservación de uno de los programas de PSA más grandes del mundo por medio del uso de un conjunto de datos empíricos a largo plazo, un modelo de hábitat con base satelital y análisis espaciales auto-regresivos sobre las medidas*

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directas del cambio en un servicio ambiental (es decir, el suministro de hábitat para especies de fauna). El hábitat del panda gigante (Ailuropoda melanoleuca) *mejoró en la Reserva Natural Wolong en China después de la implementación del Programa de Conservación de Bosques Naturales. La mejoría fue más pronunciada en las áreas monitoreadas por los residentes locales que en aquellas monitoreadas por el gobierno local, pero solamente cuando se proporcionó un pago mayor. Nuestros resultados sugieren que la efectividad del programa de PSA depende de quién recibe el pago y si el pago proporciona incentivos suficientes. Mientras el compromiso de los residentes locales no se ha incorporado a muchas estrategias de conservación en otras partes de China o del mundo, nuestros resultados también sugieren que el uso de una estrategia basada en incentivos como complemento a estrategias basadas en comando-y-control, comunidad y normas puede ayudar a alcanzar una mayor efectividad de conservación y a proporcionar una solución potencial para el conflicto de parque versus personas.*

Palabras Clave: conflicto parque-habitantes, dinámicas espacio-temporales, monitoreo de bosques, panda gigante, Programa de Conservación de Bosques Naturales, recuperación de hábitat, Reserva Natural Wolong

Introduction

Protected areas have long been the leading instrument for conserving biodiversity worldwide (Naughton-Treves et al. 2005). However, by limiting or entirely excluding human access to natural resources without sufficient respect for people's livelihoods, this "fences-and-fines" strategy has sometimes had negative social and economic impacts on the people living in and around protected areas (Adams et al. 2004; McShane et al. 2011) (see also positive impacts reported by Andam et al. 2010 and Canavire-Bacarreza & Hanauer 2013) and thus generated conflicts between natural resource use and conservation (so-called park vs. people conflict). Such conflicts escalate as the amount of protected area increases in response to the loss of biodiversity (Bertzky et al. 2012) and as human populations and resource demand continue to grow (Seppelt et al. 2014). At the same time, conservation science has undergone a paradigm shift from viewing humans as separate from nature to viewing humans as an important component in coupled human and natural systems (Liu et al. 2007, 2015). Consequently, people-oriented conservation activities are rapidly becoming widespread. By providing alternative livelihood options that reduce the pressure on biodiversity and lead to sustainable use of natural resources, community-based conservation programs have been developed with the goal of simultaneously protecting biodiversity and sustaining human livelihoods (Hughes & Flintan 2001; Berkes 2004). However, many community-based programs are often criticized for the lack of explicit conservation goals (Ferraro 2001) or for failing to achieve their goals (Hughes & Flintan 2001; Adams et al. 2004). The ineffectiveness of biodiversity conservation has resulted in calls for stricter management of protected areas and provoked the heated biodiversity-protection versus poverty-alleviation debate (Miller et al. 2011).

At the end of the 20th century, payments for ecosystem (or environmental) services (PES) emerged as a new policy tool for biodiversity conservation (Ferraro & Kiss 2002). By providing economic incentives for local people to reduce resource extraction or actively participate in conservation (Ferraro & Kiss 2002; Engel et al. 2008), PES is considered a potential solution to the park-versus-people conflict (Miller et al. 2011). However, although studies have theoretically indicated the effectiveness and efficiency of PES in biodiversity conservation (Ferraro & Kiss 2002; Wunder 2007; Chen et al. 2010), empirical evidence is inconclusive, partly due to the lack of rigorous, quantitative assessments (Wunder et al. 2008; Pattanayak et al. 2010). Although several calls have been made for empirical assessments (Ferraro & Pattanayak 2006; Pattanayak et al. 2010; Baylis et al. 2015), rigorous impact evaluations of conservation policies have only recently become available (e.g., Arriagada et al. 2012; Yang et al. 2013*b*; Ferraro et al. 2015). Furthermore, although most empirical assessments measure changes in proxies of ecosystem services (e.g., forest cover), few assessments explicitly evaluate the associated effects on actual ecosystem services delivered, especially on the provision of habitat for wildlife species (but see Clements et al. 2010).

The park-versus-people conflict is particularly relevant in China, one of the most populated and biologically diverse countries in the world. In response to biodiversity loss, the number and spatial coverage of protected areas in China have increased exponentially since the 1980s (Liu & Raven 2010). Because conventional fences-and-fines and top–down management approaches are prevalent throughout these protected areas (Liu & Diamond 2008), the livelihoods of tens of millions of rural people living in and around protected areas are often negatively affected (An et al. 2001; Xu & Melick 2007). Given this inadequate consideration of local people's dependence on natural resources and the potential for conflict (Yang et al. 2013*a*), failures in biodiversity conservation are common in China's protected areas, even in flagship reserves (Liu et al. 2001, 2015).

In 1998, the Natural Forest Conservation Program (NFCP), which is considered one of the world's largest

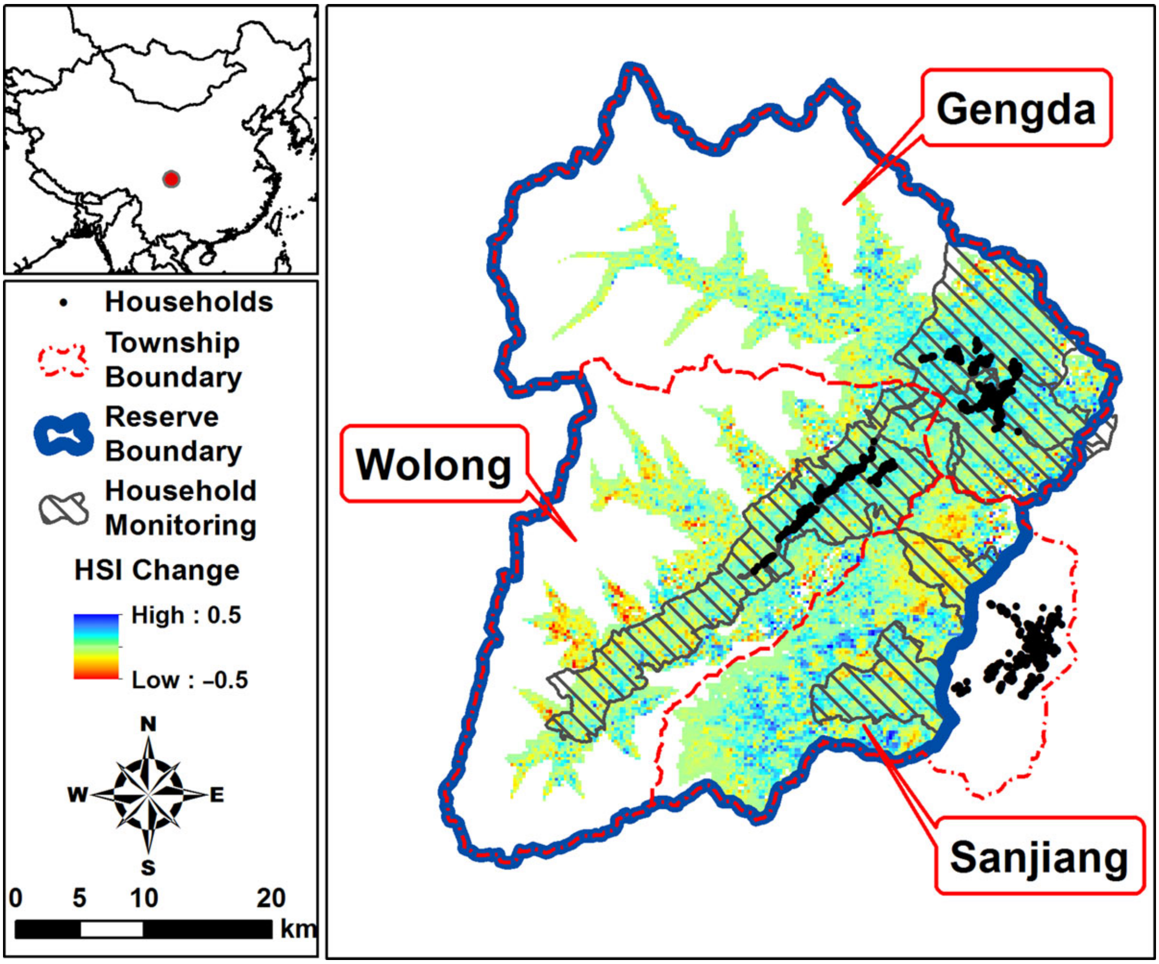

Figure 1. Spatial patterns of changes in values of the giant panda habitat suitability index (HSI) from 2001 to 2007 in Wolong Nature Reserve, China. Value changes were calculated from the outputs of a satellite-based panda habitat model (Tuanmu et al. 2011). Locations of households and household-monitored forest parcels in the 3 townships (Gengda, Wolong, and Sanjiang) comprising the reserve are also shown.

PES programs (Liu et al. 2008; Schomers & Matzdorf 2013), was implemented in China. It provides payments to forest enterprises, local governments, and in few cases individual households as compensation for their economic losses due to a shift from timber harvesting to conservation-based forest management (Yin & Yin 2010). The NFCP has increased forest cover (Viña et al. 2011; Yang et al. 2013*b*; Chen et al. 2014) and is believed to have contributed to biodiversity conservation (Loucks et al. 2001; Liu et al. 2008). However, although forest loss is a good indicator of habitat loss and degradation for forest-dwelling species, an increase in forest cover does not necessarily indicate habitat improvement because forest cover alone may not be a sufficient determinant of the presence of habitat. Therefore, we sought to fill the gap in empirical assessments of PES effectiveness with direct measures of a PES-induced change in an ecosystem service. Specifically, we empirically and spatially explicitly assessed the NFCP effectiveness in conserving and restoring the habitat of a global conservation icon, the endangered giant panda (*Ailuropoda melanoleuca*), in a world-renowned protected area, the Wolong Nature Reserve (Fig. 1). We also investigated the factors influencing program effectiveness and considered the implications of this case for broader use of PES as a tool to solve the park-versus-people conflict.

Methods

Study Area and NFCP Implementation

Established in 1963, Wolong Nature Reserve was expanded in 1975 to encompass its current area of approximately 2000 km^2. It contains over 4000 and 2200 plant and animal species, respectively (Schaller et al. 1985), including approximately 10% of the entire wild giant panda population (State Forestry Administration 2006). The reserve encompasses all of Wolong and Gengda Townships and part of Sanjiang Township (Fig. 1). All residents of Wolong and Gengda (approximately 4900 in 1200 households) live inside the reserve, whereas all residents of Sanjiang (approximately 4000 in 1100 households) live immediately outside the reserve (Fig. 1). Before NFCP implementation, agriculture was the main economic activity and fuelwood was the major household energy source in the 3 townships. Despite continued conservation efforts, from the 1960s to the late 1990s this reserve failed to protect panda habitat from human disturbance (Liu et al. 2001; Viña et al. 2007).

Since 2001, NFCP has been fully implemented in Wolong Nature Reserve. While in most of China NFCP only involves state-owned forestry enterprises and local governments (Liu et al. 2008), in Wolong Nature Reserve it involves both the local government and local residents. Approximately one-third of the total NFCP monitoring area (approximately 400 of 1205 km^2) was assigned to about 250 household groups of various sizes for monitoring activities (Fig. 1) (Yang et al. 2013*c*). The remaining area is monitored by the local government, as is characteristic of NFCP implementation in other places. Each participating household in Wolong and Gengda receives an annual payment of approximately ¥900 (about US$110, corresponding to approximately 8% of household annual income in the 2 townships in 2001) to monitor and report illegal forest harvesting in assigned forest parcels. Households in Sanjiang receive about half of the amount paid to households in Wolong and Gengda townships.

This differential payment approach is an administrative consideration. Households in Wolong and Gengda are managed by the Wolong Administrative Bureau, whereas households in Sanjiang are not. However, given that households in Sanjiang are potential threats to forests and panda habitat, the Wolong Administrative Bureau still would like to engage them in NFCP monitoring and thus offered them half of the payment that the households in Wolong and Gengda received. Although the lower payment comprises a similar contribution (approximately 8%) to their household annual income, the residents in Sanjiang are required to travel longer distances to reach their assigned parcels (Fig. 1). Therefore, while the relative size of the payment to the mean household annual income is similar among the 3 townships, the relative payment in Sanjiang is considerably lower both in absolute amount and in its ratio to total household income once travel costs are included. The same payment reduction (i.e., penalty) is applied to every household within a monitoring group if anthropogenic damages are found in the forest parcels assigned to the group (Yang et al. 2013*c*). Due to differences in administration (i.e., government vs. household monitoring) and reward systems (i.e., higher vs. lower payments), Wolong Nature Reserve offers an excellent opportunity to evaluate the influence of distinct implementation conditions on the conservation effectiveness of NFCP.

Spatiotemporal Dynamics of Giant Panda Habitat

To investigate the spatiotemporal dynamics of giant panda habitat, we used a satellite-based habitat model (Tuanmu et al. 2011) to estimate the suitability for giant pandas of every 250 × 250 m pixel throughout the reserve in 2001 (after the full implementation of the NFCP) and 2007 (before the devastating Wenchuan Earthquake in 2008). The habitat model is particularly useful for characterizing giant panda habitat because it is based on information about the most important landscape determinants of panda habitat (i.e., forest cover and bamboo distribution [Tuanmu et al. 2010]). We then calculated the change in habitat suitability index (HSI) values (ranging from 0 to 1, with higher values indicating greater suitability) obtained from the habitat model for the 2 years (i.e., 2007 value minus 2001 value) for each pixel. We also estimated the areal change in habitat in the entire reserve by applying a threshold to convert the continuous HSI scale into a binary outcome (i.e., habitat or nonhabitat). Details of these procedures are in the Supporting Information.

Effects of NFCP Implementation

To analyze the effects of NFCP on the spatiotemporal dynamics of panda habitat, we used the pixel-level changes in HSI between 2001 and 2007 as a measure of the effects of NFCP implementation and used spatial simultaneous autoregressive error models (SEMs) to spatially relate the HSI changes to different NFCP implementation approaches (i.e., government monitoring or household monitoring with high or low NFCP payments) (Table 1) at the pixel level. The SEMs allow the value of the response variable (i.e., HSI changes) at a given location to be dependent on the values at nearby locations and include a spatially weighted error term in the regression under the assumption that the dependency exists in the model residuals (Dormann et al. 2007). To control for potential confounding effects, the models included several biophysical and anthropogenic factors (Table 1), which are important for determining the spatiotemporal dynamics of forests and panda habitat in the reserve (Liu et al. 1999; Bearer et al. 2008; Viña et al. 2011). We also included the HSI values in 2001 to account for the potential dependence of HSI changes on initial values. Information on the data and processing approaches to obtain these factors is provided in Table 1. Details on the implementation of these models, model diagnostics, and model selection are in Supporting Information.

Because it is impossible to identify a suitable area as a counterfactual to indicate what would have happened without the policy effects due to its nationwide implementation, here we adopted a nonexperimental study design with a before- versus after-policy comparison (Yang et al. 2013*b*). By using after-policy habitat change as the

Table 1. Independent variables included in regression models that relate changes in panda habitat suitability index (HSI) values with implementation of Natural Forest Conservation Program (NFCP) and other biophysical and anthropogenic factors.

Variable	*Unit*	*Description*	*Mean (SD)*
HSI_2001	unitless	value of habitat suitability index (range: 0–1) in 2001 for each pixel (250 × 250 m) of the HSI map (HSI pixel)	0.37 (0.20)
FC_2001	%	percentage of forested pixels (30 × 30 m) of a binary forest cover map derived from a 2001 Landsat TM image (Viña et al. 2007) within the surrounding 8 pixels of each HSI pixel	59.28 (27.48)
Elevation	m	average elevation over the pixels (90 × 90 m) of a digital elevation model (DEM) from the Shuttle Radar Topography Mission within each HSI pixel	2765.91 (528.53)
Roughness	m	standard deviation of elevation over the DEM pixels within each HSI pixel	51.83 (17.28)
Aspect north	degree	deviation from north (0°–180°)	92.71 (51.75)
Aspect east	degree	deviation from east (0°–180°)	85.62 (51.78)
CTI	m²/radian	compound topographic index, a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction (Moore et al. 1993)	10.94 (2.08)
Dist2Household	m	Euclidean distance from each HSI pixel to the nearest household	7195.76 (5643.73)
Dist2Road	m	the nearest Euclidean distance from each HSI pixel to paved roads	5920.22 (4827.59)
Monitoring type	dummy	NFCP monitoring type: government monitoring (reference); household monitoring	government: 12,585 pixels household: 7,955 pixels
Payment level	dummy	different NFCP payments: no payment (i.e., monitored by the local government) (reference); low payment (i.e., monitored by households in Sanjiang township); high payment (i.e., monitored by households in Wolong and Genda townships)	no: 12,585 pixels low: 1,454 pixels high: 6,501 pixels

effect measure, we assumed that panda HSI values would remain unchanged from 2001 to 2007 if NFCP had not been implemented. This assumption is needed because our habitat model relies on remotely sensed imagery available only after February 2000; thus, before-policy habitat change cannot be obtained using the same model. While this assumption is not expected to reflect reality, it provides a lower bound of the actual habitat change caused by the implementation of NFCP. This is because the continuous habitat loss and degradation observed in the reserve before policy implementation (Liu et al. 2001; Viña et al. 2007; also see Supporting Information) suggests a negative habitat trend without NFCP. Therefore, the result of our assessment of NFCP effects on panda habitat tends to be conservative.

Results

From 2001 to 2007, Wolong Nature Reserve experienced an overall improvement in panda habitat. According to our habitat model, the mean HSI value increased approximately 7.1% (from 0.366 to 0.392). The total habitat area increased 3.4% (from 686 to 709 km^2) during the same period (Supporting Information). However, considerable spatial variability in HSI changes was observed across the reserve. For example, large HSI increases occurred near human settlements in Wolong and Genda Townships, whereas large HSI decreases occurred to the north of Sanjiang Township (Fig. 1).

The spatial variability was significantly related to different NFCP implementation approaches. Our spatial regression models showed that the increase in HSI values within household-monitored areas was roughly 2.5 times as large as that within government-monitored areas during the same period when the other variables were controlled (i.e., at their mean values) (SEM 1 in Table 2). The models also indicated that the effect of household monitoring depended on payment level (SEM 2 in Table 2). Under the high payment level, the increase in HSI within household-monitored areas was roughly 3 times as large as that within government-monitored areas, controlling for other variables. However, there was no significant difference in HSI change between the areas under

Table 2. Summary of spatial simultaneous autoregressive error models (SEM) that relate the changes in panda habitat suitability index (HSI) values with a set of independent variables.

Variable	Mean standardized coefficient (lower and upper bounds of 95% CI)[a]	
	SEM 1	SEM 2
Intercept	0.016 (0.005, 0.027)*	0.015 (0.004, 0.025)*
HSI_2001	−0.086 (−0.097, −0.075)*	−0.086 (−0.097, −0.075)*
FC_2001	0.021 (0.012, 0.029)*	0.021 (0.013, 0.029)*
Elevation	−0.047 (−0.058, −0.036)*	−0.048 (−0.059, −0.037)*
Roughness	−0.004 (−0.012, 0.005)	−0.004 (−0.012, 0.004)
Aspect_north	0.011 (0.003, 0.019)*	0.011 (0.003, 0.019)*
Aspect_east	0.0003 (−0.006, 0.007)	0.0002 (−0.006, 0.006)
CTI	−0.007 (−0.014, 0.0001)	−0.007 (−0.014, −0.0001)*
Dist2Household	−0.014 (−0.025, −0.004)*	−0.015 (−0.026, −0.004)*
Dist2Road	−0.008 (−0.016, 0.001)	−0.003 (−0.013, 0.008)
Monitoring type		
household versus government monitoring	0.023 (0.003, 0.044)*	
Monitoring type under different payments		
low payment versus no payment		−0.004 (−0.042, 0.034)
high payment versus no payment		0.033 (0.012, 0.055)*
Autoregressive term	0.559 (0.486, 0.633)*	0.537 (0.451, 0.623)*
Moran's I of residuals[b]	−0.008 (−0.014, −0.001)	−0.007 (−0.013, −0.001)
Akaike information criterion	−1608 (−1709, −1507)	−1609 (−1710, −1509)

[a]*Values obtained from 100 replicates of each model with the bootstrapping approach. Asterisks indicate the mean values that are significantly different from 0 ($p < 0.05$). The response variable and dummy variables (i.e., monitoring type and payment level) were not standardized.*
[b]*Tested against its expected value of −0.001, indicating no significant spatial autocorrelation problem.*

government monitoring and those under household monitoring with the low payment (SEM 2 in Table 2).

Besides different NFCP implementation, several confounding factors were also significantly related to the changes in HSI (Table 2). For instance, increases in panda HSI values tended to occur more often in areas situated on south-facing slopes, at lower elevations, surrounded by forests, and closer to local households (Table 2). However, there was a negative relationship between HSI change and initial HSI values (i.e., in 2001) in part because pixels with higher initial values had less room to increase.

Discussion

Our results show improvement in the habitat of an endangered species after the implementation of a PES program in a reserve where the command-and-control strategy alone had failed to protect the habitat for over 30 years (Liu et al. 2001; Viña et al. 2007). With direct measures of changes in the provision of an ecosystem service (i.e., provision of habitat for giant pandas), our assessment indicates that observed forest recovery due to the NFCP implementation (Yang et al. 2013*b*) can translate into panda habitat improvement. To the best of our knowledge, ours is the first empirical and spatially explicit assessment of the effects of this program on habitat dynamics of a wildlife species.

The improvement of panda habitat was modest due to the relatively short temporal window since program implementation and to potential time lags between conservation actions and outcomes. However, the improvement runs counter to the trend of habitat loss and degradation observed between the 1960s and 2001 (Liu et al. 2001; Viña et al. 2007), which suggests the conservation effectiveness of NFCP. The negative before-policy trend also suggests that our assessment seems to be underestimating the beneficial effects of NFCP implementation on panda habitat because we assumed unchanged habitat without NFCP implementation. However, the before-policy habitat trend was obtained using a different habitat model (Liu et al. 1999), which was driven mainly by forest cover change because MODIS imagery for the more comprehensive model we used is unavailable before 2000. However, the negative before-policy trend indicates that forest loss drove habitat change during that period. Forest loss is a good indicator of panda habitat loss because giant pandas seldom use unforested areas and the bamboo eaten by pandas also needs shading by canopy trees (Schaller et al. 1985). Therefore, even without bamboo information, this model is suitable for capturing the before-policy habitat dynamics.

One potential limitation of using the historical trend as a baseline is that it might ignore other factors that also varied during the study period. However, although other conservation policies and socioeconomic dynamics have occurred coincidentally with NFCP, they have made less direct contribution to panda habitat recovery relative to NFCP. For example, another major conservation policy implemented in the reserve since 2000 is the Grain-to-Green Program (GTGP) (Chen et al. 2010). This program provides local farmers with cash or grain subsidies to encourage the conversion of cropland on steep slopes to forest or grassland (Liu et al. 2008; Yin & Yin 2010). The GTGP may produce long-term benefits for the conservation of forests and forest species through indirect effects (e.g., promoting outmigration of agricultural surplus labor) (Uchida et al. 2009). However, its direct contribution to panda habitat recovery in the reserve is negligible because GTGP-enrolled cropland comprises <1% of the reserve (Wolong Nature Reserve 2005) and the tree seedlings and saplings planted cannot provide panda habitat, at least within the time frame of our assessment (Bearer et al. 2008).

Demographic dynamics and associated changes in resource demand would also not explain the reversal in the trend of panda habitat degradation. Between 2001 and 2007, human population increased approximately 6% and the number of households increased 23% in the 3 townships (Wenchuan Statistics Bureau 2008). Both these changes suggest an increase in resource consumption (Liu et al. 2003*a*), which is expected to translate into further degradation of panda habitat without NFCP implementation (An et al. 2001; Viña et al. 2011). Some socioeconomic changes (e.g., diversification of income sources, energy transition from fuelwood to electricity) have influenced local people's dependence on natural resources (Chen et al. 2012; Yang et al. 2013*a*). However, rapid changes did not appear in the reserve until after NFCP implementation, and some of the changes were directly or indirectly triggered by the NFCP (Yang et al. 2013*b*).

Besides showing overall habitat improvement, by correlating spatial variability of the observed habitat dynamics with different NFCP implementation approaches, our assessment also indicates that engaging local residents in forest monitoring through payments more effectively conserves panda habitat than paying the local government to monitor illegal forest use. Because the positive effect of local engagement depends on the payment level, these results show the critical role of economic incentives in determining the conservation effectiveness of this program. They also indicate the importance of who receives the payment and whether the payment is sufficient to provide strong incentives in the design of a PES program.

Although the assumption of unchanged habitat without NFCP implementation exhibited an influence on our analyses of the spatial heterogeneity of NFCP effects, it did not change our conclusions. Because greater before-policy forest loss was observed within the parcels monitored under the high payment level than in low payment parcels (Supporting Information), the assumption tends to result in a greater underestimation of NFCP-induced habitat improvement within the high-payment parcels than in the low-payment parcels. Therefore, our assessment tends to underestimate the significance of payment levels in determining NFCP effects on panda habitat. Although the assumption tends to lead to an overestimation of the positive influence of household monitoring on NFCP effects due to less observed before-policy forest loss in household-monitored areas than in government-monitored areas, an adjustment for the overestimation does not likely cancel out the positive influence. When confounding effects of the other independent variables were controlled (i.e., at their mean values) using SEMs, the before-policy forest loss in government-monitored parcels was 1.6 times greater than in household-monitored parcels and the after-policy habitat improvement within government-monitored parcels was 2.4 times lower than in household-monitored parcels (Supporting Information). Therefore, although the actual influence of monitoring types is probably weaker than what our model indicates, there was still a significant positive influence of household monitoring on NFCP-induced habitat improvement.

Three potential reasons may explain the effectiveness of the incentive-based approach. First, direct payments to local residents may compensate for the costs of forgoing resource-depleting activities and thus create stronger conservation incentives (Engel et al. 2008). Second, the payments may enhance the effectiveness of other policies. For example, in 2002 a hydropower plant was built in Wolong to provide electricity for local residents. The NFCP payments increased the affordability of local residents to use electricity, thus reducing the use of fuelwood as the primary energy source (Yang et al. 2013*b*). Finally, by assigning forest monitoring parcels to household groups rather than to individual households, the reserve administration may have forced a shared responsibility in which sanctions among households in a monitoring group may enhance rule compliance through social norms and networks (Chen et al. 2009; Yang et al. 2013*c*). Thus, households may fulfill their monitoring duties to avoid payment reductions that could harm their social relations with other members of the same monitoring group. Households may also avoid causing damages on the parcels monitored by other groups to maintain good social relations with households in those groups (Yang et al. 2013*c*).

Although biodiversity conservation is not the main aim of the NFCP, we empirically showed that besides protecting and restoring forests (Liu et al. 2008), the NFCP can also be more effective in restoring the habitat of an endangered wildlife species by engaging local residents in conservation through direct payments. In most of China, local residents do not directly participate in NFCP implementation (Yin & Yin 2010), so additional benefits (e.g., protecting biodiversity) can be achieved if this successful local, incentive-based approach is applied in other regions.

While rigorous impact evaluations of PES programs, especially with direct measures of ecosystem services, are still largely missing in the current literature (Ferraro et al. 2015), our study enriches the knowledge pool of evidence-based conservation and provides broad implications for the design and applications of PES programs. Our results indicate the importance of program design (e.g., amount of payments, receivers of payments, and enforcement approaches) in determining the effectiveness of a PES program. With the assignment of monitoring duties to groups of households, NFCP provides a good example of a combination of incentive- and norm-based strategies. Our results also suggest that PES programs acting in tandem with command-and-control strategies are more effective at conserving wildlife habitat than command-and-control strategies acting alone. Compensations obtained through PES programs may facilitate compliance of command-and-control regulations, whereas command-and-control regulations may increase costs for not participating in PES programs (Engel et al. 2008). Furthermore, the additional cost of checking program compliance and conservation outcomes under PES programs can be minimized if these activities are conducted through the regular patrols of nature reserve officials. Therefore, PES programs not only provide a framework for community-based conservation (Nelson et al. 2010) but could also complement other conservation instruments.

Although our empirical data were from a local reserve for the giant pandas, the PES program evaluated is a national program in China. Furthermore, many previous findings and methods developed in the reserve have been applied to other places at the local (e.g., DeFries et al. 2007; Carter et al. 2014), regional (e.g., Viña et al. 2010), national (e.g., Liu et al. 2003*b*), and global scales (e.g., Liu et al. 2003*a*; Liu 2013). Thus, it is our belief that insights from our study are broadly applicable. We acknowledge the limitations of the single-context perspective of our study, but we believe it provides a good foundation for more rigorous impact evaluations of conservation programs across different contexts. More such studies will lead to a better understanding of the performance and underlying mechanisms of conservation interventions. Such understanding can help resolve the park-versus-people conflict and achieve more effective conservation of ecosystem services.

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Supporting Information

Details of the giant panda habitat model (Appendix S1), the analysis of the effects of NFCP implementation (Appendix S2), and the evaluation of potential influences of assessment assumptions on the results (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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