LETTER

A win-win strategy for ecological restoration and biodiversity conservation in Southern China

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Abstract

Environmental degradation and poverty are linked, and must be tackled together. Doing so requires a win-win strategy that both restores the environment and ensures a sustainable livelihood for those who are affected by the restoration project. To understand the importance of combining ecological restoration and biodiversity conservation objectives with a consideration of the livelihoods of residents, we examined a successful project in ecologically fragile Changting County, Fujian Province, China. We attribute the project’s success to the development of a win-win strategy that sustainably improved resident livelihoods, in contrast with traditional strategies that focus exclusively on establishing forests and grassland. To develop this win-win strategy, we performed long-term monitoring (since 1984) under a program designed to permit ecological restoration and biodiversity conservation in the county. For our analysis, we chose a range of natural and socioeconomic indicators that could affect the ecological restoration; we then used a contribution model to identify the relative influence of each social, economic, or environmental factor on the dependent variables (vegetation cover, soil erosion, number of plant species). The results showed that by improving livelihoods and mitigating poverty in the long term, the project also reduced damage to the environment by local residents. Our calculations suggest that accounting for socioeconomic factors played a key role in the successful ecological conservation. This win-win path to escaping the poverty trap during ecological restoration provides an example that can be followed by restoration projects elsewhere in the world with suitable modifications to account for unique local conditions.

Introduction

Ecologically fragile regions face the simultaneous problems of environmental degradation and poverty (Tallis et al 2008). Due to a lack of alternatives, residents of these areas are often forced to engage in unsustainable activities such as deforestation, overgrazing, and cultivation of land that is unsuitable for agriculture, thereby causing environmental degradation (Sietz et al 2011). However, the resulting environmental degradation also decreases the productivity of the land, thereby exacerbating poverty and continuously reducing farmer income. This interaction of poverty and environmental degradation creates a vicious circle known as the ‘poverty trap’, in which poverty leads to environmental degradation, and environmental degradation then deepens poverty (Tallis et al 2008). However, traditional ecological restoration and biodiversity conservation projects did not help farmers escape the poverty trap because they focused on restoration of the degraded ecosystem and ignored the livelihoods of the residents affected by the projects (Sachs and Reid 2006, Beddington et al 2007).

This can be particularly problematic in large-scale projects. For example, severe flooding in 1998...
prompted the implementation of China’s Natural Forest Conservation Program to prohibit logging of natural forests and sustain their role in water conservation and flood prevention. The program was intended to slow or prevent deterioration of the ecological environment and protect biological diversity, but did not include a component to promote sustainable social and economic development (Liu 2010). Such policies inevitably reduce the goods and services provided to the local community by forests and grasslands (Wang et al. 2007), making their long-term success doubtful. Similarly, China’s national Grain for Green program, initiated in 1999, promoted forest conservation, afforestation, and grassland establishment by providing subsidies to the farmers displaced by the program, but the subsidies will end when the program ends in 2024, without creating new forms of employment. As a result, the displaced farmers will have no choice other than to return to their former unsustainable practices (Cao 2011). Therefore, the result of this program will be an exacerbation of poverty (Cao et al. 2009).

Though even impoverished people may understand that ecological restoration and biodiversity conservation are valuable policy goals, the most impoverished may have no choice other than to ignore the policy (Castilla and Defeo 2005, Zhang et al. 2010). Some will avoid the policy’s constraints, whereas others will carry on ecological restoration during the implementation of the project, but when the project ends, will return to their old routine. Therefore, the problem of ecological degradation will continue due to the lack of a long-term commitment (Gauvin et al. 2010). Unfortunately, most policies that provide funding for environmental remediation are short-term and only provide money for remediation activities (Serageldin 2002). As a result, the funding ends once the planned remediation is complete, without providing new livelihoods to replace the livelihoods that were lost under the policy. Previous research has shown that under these circumstances, residents are likely to return to their previous activities when they can no longer survive solely on the government subsidies, thereby eliminating any gains from the project (Cao 2011). Therefore, solving these problems requires policy developers and implementation managers to design a win-win strategy that balances the needs of the poorest people who will be affected by a policy (i.e. those who lack sufficient income to obtain the basic necessities of life, such as food, medical treatment, clothing, and other necessities such as education for their children) with the need for ecological conservation.

To develop a suitable win-win strategy, we performed long-term monitoring (since 1984) under a program designed to promote ecological restoration and biodiversity conservation in China’s Changting County. This program comprised two phases, each with a different strategy. From 1984 to 1999, before the time of the present study, the county planted large areas of grassland and forest to protect soil from erosion and conserve water. Starting in 1999, we encouraged four townships (Cewu, Hetian, Sanzhou, and Zhourian) that have experienced the worst land degradation to adopt a new win-win strategy that balanced the needs of the poor to earn a living with the need for ecological restoration. In contrast, the 14 other townships outside the new project area continued to follow the old strategy (Cao et al. 2009).

The win-win strategy

Our research area is located in a warm and wet part of China’s Changting County (25°18’40″ to 26°02’05″N, 116°00’45″ to 116°39’20″E) that covers 309,720 ha in western Fujian Province. Changting County is atypical impoverished region in southern China. The net per capita income of rural residents in 2015 was RMB 11658, which is 53.1% of China’s average (RMB 21966). This index is RMB 2576 per capita; which is 44.0% of China’s average (RMB 5854) in 1999. Because this region has been historically impoverished, it became one of the seminal regions for the emergence of China’s Communist Party. During China’s civil war between the Kuomintang and the Communist Party from 1929 to 1934, the region suffered severe socioeconomic and ecological damage. However, the vegetation cover has recovered slowly because of the favorable ecological environment; the total precipitation is high (1730.4 mm yr−1) and temperatures are warm (an annual mean of 18.3°C and a minimum of 7.9°C) based on meteorological data collected at a soil and water conservation monitoring station established in 1940 in the study area.

From 1958 to 1978, the region suffered from a national policy to prioritize grain production through conversion of forests into cultivated fields, combined with planting of monoculture crops. As a result of these measures, species diversity and vegetation cover decreased greatly, thereby increasing the frequency and scale of water erosion of soil and the severity of floods; the combination of these factors has led to additional degradation of the county’s forests and landscape. This, in turn, exacerbated the soil erosion problem. The area that was experiencing serious erosion (>8000 t km−2 yr−1) increased by 5.1% annually, from 47,870 ha in 1966 to 97,470 ha in 1985 (Cao et al. 2009).

To alleviate this land degradation, the county’s government reformed property rights for forested land starting in 1985, with ownership of 90% of forested lands allocated to individual farmers for afforestation. However, the policy failed to prevent additional environmental damage. The area experiencing soil erosion decreased by 23.3% between 1985 and 1995, but the area experiencing severe soil erosion (>8000 t km−2 yr−1) increased by more than 100%, reaching a
total of 112.1 km² during this period of only 10 yr; during the same period, the vegetation cover and forest cover both decreased by 2% of the total area despite the large-scale planting program (Cao et al. 2009).

To find a set of environmental and economic improvements that could lead to a win-win strategy that sustainably improved the livelihoods of residents of the county, and to provide a contrast with traditional strategies that focused exclusively on establishing forests and grassland, we selected four townships (Cewu, Hetian, Sanzhou, and Zhuotian) for implementation of a new strategy. Under this strategy, the farmers would receive living subsidies that compensated them for abandoning the harvesting of forests (i.e. reimbursement for their loss of access to the wood) and for their efforts in ecosystem restoration, as was the case under existing programs, but the win-win strategy included four new elements:

1. To move the farmers away from a form of forestry that focused on harvesting fuelwood, the government implemented a policy to provide alternative fuel for cooking (i.e. methane). This strategy was encouraged by the construction of a household-scale infrastructure for the production and use of methane-generation facilities for every household by providing compensation ranging from RMB 1000 for <8 m³ of capacity to RMB 1500 for >8 m³ of capacity. To change the behavior of residents, they were fined RMB 1000 each time they were caught harvesting trees and other natural vegetation for fuel. Here and in the subsequent three points, the government encouraged adoption of the new strategy by providing incentives and by penalizing bad behavior.

2. To increase resident income, the government encouraged the development of private-sector village-scale enterprises that also provided benefits for ecological conservation. For example, to encourage the raising of pigs and fish indoors instead of grazing them on damaged land, the government provided compensation of RMB 100 for each additional pig and RMB 15 000 for each 1 h a fish pond. This approach let villagers raise high-quality food animals, increased their income without damaging the environment, and provided organic fertilizer (manure and wastewater from aquaculture) to increase crop yields without requiring expensive inorganic fertilizers. One key aspect of this approach was that the government subsidies created private-sector industries (e.g. indoor animal husbandry) that would continue to provide income after the government subsidies ended.

3. To improve the environmental restoration, residents were encouraged to develop ‘green’ enterprises that would produce products from the land without causing ecological damage. Specifically, the government encouraged the establishment of fruit orchards. Planting of fruit trees was encouraged by providing compensation of RMB 1500 ha⁻¹. To encourage the use of organic fertilizers, the government supported the establishment of enterprises that organized the community to work together to produce this resource from the increased manure supply provided by raising livestock indoors.

4. The government agreed to perform additional planning related to the construction of rural roads in the new project area to facilitate the transportation of seedlings, fertilizer, and workers, as well as to provide easier access to markets for the farmers’ crops.

Methods of analysis

To analyze the results of the new strategy, we chose a range of natural and socioeconomic indicators that could affect the ecological restoration: (1) rural social development indicators, including the rural population, the lengths of roads, the farmland area, and the rural population; (2) rural economic development indicators, including rural net income, the number of fish ponds established, the number of methane-generating facilities, the number of livestock, the annual harvest of grain crops, and the orchard area; (3) environmental policy indicators, Including the afforestation area, the area in which grazing was forbidden, and the investment in ecological restoration; and (4) climatic and environmental indicators, including the mean annual temperature and total annual precipitation.

To account for the effects of different units of measurement for these factors, we normalized the data by dividing the value in a given year by the value at the start of the study period, in 1984. We then used stepwise regression for the relationships between three ecological indicators (vegetation cover, soil erosion, and number of plant species) and the abovementioned variables to identify the key factors and their contribution to each of these indicators. To avoid the effect of overlapping factors (multicollinearity) we used stepwise regression to eliminate the least important variables. For this analysis, we used version 13.0 of the STATA software (www.stata.com). Our analysis showed that the rural population, rural net income, farmland area, area of fruit tree orchards, area in which grazing is forbidden, afforestation area, number of livestock, number of methane-generation facilities, length of roads, mean annual temperature, and precipitation were the main indicators for all three dependent variables. We used the following regression model to identify these factors:

\[ y_t = \alpha + b x_t + u_t \] (1)

where \( y_t \) is the dependent variable (vegetation cover, soil erosion, and number of species per plot) in year \( t \),
\( x_i \) is the social, economic, or environmental factor responsible for causing the change in \( y \) in that year, \( u_i \) is an error term, and \( a \) and \( b \) are regression coefficients. We used the Durbin-Watson test to identify autocorrelated variables and remove the variables with the least impact on the dependent variables.

We used a contribution model to identify the influence of each social, economic, or environmental factor on the dependent variables (vegetation cover, soil erosion, and number of species per plot). The contribution of a given variable was calculated as follows:

\[
\text{Con}_i = \frac{|\text{SCV}_i|}{\sum |\text{SCV}_j|} \tag{2}
\]

where \( \text{Con}_i \) represents the contribution of influence factor \( i \) to the total effect, and \( \text{SCV}_j \) is the value of parameter \( i \) that is obtained after transforming the data to have a normal distribution with a mean of 0 and a standard deviation of 1 (Feng et al. 2015).

Climate data (temperature and precipitation) were obtained from the China Climate Yearbook (1984–2015). Rural net income in a given year was converted to 2015 values to allow a comparison among years using consumer price index data for Fujian Province since 1984, which we obtained from the Fujian Statistical Yearbook (1984–2015). The data on road lengths was based on county-level inventories at the end of each year. The data on areas in which grazing was forbidden area was based on the amount implemented in a given year.

To assess the vegetation cover at the study sites, we measured both the crown area of the trees and the vegetation cover by understory vegetation (only green plants, therefore photosynthetically active vegetation). To provide a comparison between the old and new strategies, the Water and Soil Conservation Bureau of Changting County selected four representative villages in four towns (Cewu, Hetian, Sanzhou, and Zhuotian; hereafter, the new project area) that were chosen to implement the new strategy because they were experiencing more severe erosion than in the rest of the county and four villages from four towns that implemented only the old strategy and that had soil erosion representative of the overall conditions in the county. In each village, vegetation cover and the number of species were monitored; the sample size was 24 artificial restoration plots in the new project area (i.e. 6 plots per village) and 30 natural restoration plots in the old project area. The plots in both areas were established in 1984, but the plots in the new project area only began to receive the new treatment in 1999. Every plot was 20 m × 20 m.

Using a steel tape, we measured the crowns of 20 randomly selected trees in each plot in each year during the middle of the growing season (between the last 10 d of June and the end of August) to determine the crown area, which we used to represent the mean crown cover per tree. We measured the maximum and minimum crown radii and modeled the crown as an ellipse, with these radii representing the semi-major and semi-minor axes, and calculated the mean canopy area for each species using geometric mean values to account for extreme values. Total tree canopy cover (the proportion of the total site area accounted for by a vertical projection of the elliptical crowns of the trees, including the leaves plus the stems and branches) was calculated by multiplying the mean crown area in a given year by the number of trees that were present in that year, then dividing this total by the total area planted with that species. Where canopies overlapped, we carefully determined the extent of the overlap and calculated its area; we then divided this area equally between the two trees to avoid double-counting (Gao et al. 2011).

In each portion of the plot that was not covered by tree or shrub canopies or where grass was growing below trees, we performed line intersect sampling using two 10 m transects at right angles to each other to survey herbaceous vegetation (ground cover). We calculated the net vegetation cover for the grass and woody cover by averaging the two cover values (i.e. for woody and herbaceous vegetation). We identified the vegetation cover every year at the same time (between the last 10 d of June and the end of August). Total vegetation cover (the combined cover of trees and herbaceous vegetation such as grasses, forbs, and herbs) for a given area was calculated by multiplying the mean cover value for a given vegetation type (woody vs. non-woody vegetation) by the proportion of the total plot area occupied by that type of vegetation.

To describe the plant species richness in the study plots, we collected samples of all plant species annually in each plot in August. The samples were brought to Fujian Normal University for identification if we could not confirm their identity in the field. Because the goal of this study was primarily socioeconomic, not ecological, plant species means the total number of plant species in the whole project area, but we have not presented them here.

In addition, 48 sedimentation ponds (run-off collection ponds) were established to monitor soil erosion rates under the new and old strategies, at 6 ponds per village, in 1999. To do so, we selected 20 m long by 5 m wide observation sections along the slopes in each test plot used to monitor vegetation cover and constructed a 15 m² stone and concrete sedimentation pond at the bottom of the slope. The quantity of runoff was measured in each pond after each rain. In addition, all of the soil was removed from the bottom of each pond 24 h after the rain, and three random samples of this soil were dried for 12 h at 105°C to determine their oven-dry weight and moisture content; this data was then used to determine the quantity of soil eroded by the rain.
Results

From 1984 to 1999, the rates of investment inside and outside the new project area increased at comparable rates, but the rate inside the new project area was about half of that outside the new project area. As a result, the vegetation cover, forest cover, and number of plant species in the new project area decreased, despite increases in these parameters outside the new project area during the same period (figure 1).

In 1999, implementation of the new policy began. Although the investment in ecological restoration in the new project area continued to be lower than that outside the new project area, the difference was much smaller (figure 2). In addition, the number of vegetation species in the new project area increased from 6 to 43 for the whole new project area, the vegetation cover increased from 42.0% to 80.5%, and forest cover increased from 45.0% to 77.6% between 1999 and 2014; outside the new project area, the corresponding increases were from 72 to 82 species per plot, from 73.0% to 88.1% vegetation cover, and from 71.0% to 82.5% forest cover (figure 2). Based on the slopes of the linear regressions, the growth rates for the number of vegetation species, vegetation cover, and forest cover in the new project area were 3.3, 2.5, and 2.8 times, respectively, those outside the new project area.

The contribution model revealed the impacts of the variables on the growth in vegetation cover, decrease in soil erosion, and increase in the number of plant species in the new project area (table 1). The construction of fruit orchards accounted for 21.8% of the increase in vegetation cover, versus 19.7% for the

![Figure 1. Investments in ecological restoration inside and outside the new project area from 1984 to 1999 in Changting County, and the corresponding changes in vegetation and forest cover and in the number of plant species.](image-url)
Figure 2. Investments in ecological restoration inside and outside the new project area from 1999 to 2014 in Changting County, and the corresponding changes in vegetation and forest cover and in the number of plant species.

Table 1. The contributions of each primary variable to the changes in vegetation cover, soil erosion, and the number of plant species from 1984 to 2014 in the new project area (Changting County, China). $r$ represents Pearson’s correlation coefficient.

| Variable                                | Vegetation cover    | Soil erosion     | Plant species number |
|-----------------------------------------|---------------------|------------------|----------------------|
|                                         | $r$                 | Contribution (%) | $r$                  | Contribution (%) | $r$ | Contribution (%) |
| Rural population                        | 0.690***            | 3.34             | -0.403**            | 7.26              | 0.390** | 2.26            |
| Rural net income                        | 0.793**             | 12.53            | -0.939**            | 23.58             | 0.876** | 20.45           |
| No. of livestock                        | 0.472**             | 3.69             | 0.532**             | 9.34              | 0.674** | 7.19            |
| Farmland area                           | 0.382**             | 19.72            | -0.038              | 11.34             | 0.256   | 9.42            |
| Fruit tree orchard area                 | 0.830**             | 21.78            | -0.523**            | 14.21             | 0.745** | 23.34           |
| Area in which grazing is forbidden      | 0.389**             | 10.47            | -0.049              | 1.11              | 0.246   | 11.00           |
| Afforestation area                      | 0.802**             | 1.25             | -0.702**            | 0.35              | 0.792** | 1.02            |
| No. of methane-generation facilities    | 0.771**             | 9.51             | -0.607**            | 1.88              | 0.779** | 13.94           |
| Length of roads                         | 0.717**             | 6.51             | -0.421**            | 22.59             | 0.619** | 1.40            |
| Mean annual temperature                 | -0.012              | 1.71             | -0.077              | 0.86              | -0.005  | 1.60            |
| Annual precipitation                    | 0.365**             | 9.49             | -0.056*             | 7.03              | 0.241*  | 8.34            |

Notes: Significance levels: ** P < 0.01, * P < 0.05, ns not significant.
area of farmland, 12.5% for rural net income, and 10.5% for grazing restrictions in degraded land. These strategies therefore accounted for 64.5% of the total change in vegetation cover. For soil erosion, rural net income contributed 23.6% of the total decrease, versus 22.6% for road length, 14.2% for the area of fruit tree orchards, and 11.5% for the farmland area; together, these factors accounted for 71.9% of the total decrease in erosion. For the number of plant species, the area of fruit tree orchards contributed to 23.3% of the total increase, versus 20.4% for rural net income, 13.9% for methane generation facilities, and 11.0% for the area in which grazing was forbidden; together, these factors accounted for 68.6% of the total increase in the number of species.

From these results, increased rural net income contributed strongly to improvements in vegetation cover, decreases in soil erosion, and increases in the number of plant species, which suggests that taking measures to increase rural net income also had strong and beneficial environmental consequences. However, other factors that related to protecting the livelihoods of residents in the long term (e.g. the area of fruit tree orchards, methane generation) also contributed strongly to the project’s success.

**Discussion**

Ecological restoration has complex and poorly understood consequences for the structure and composition of future ecosystems and socioeconomic systems (Ma et al., 2013, Feng et al., 2015). Even when the intentions of ecological restoration are good, and the restoration strategy is suitable for the environmental conditions, it is necessary to account for the program’s socioeconomic consequences (Gong et al., 2012). Particularly in a country as densely populated as China, where economic development is proceeding rapidly, it is necessary to develop strategies that provide both ecological and socioeconomic benefits (Cao, 2011). Considering both the ecosystem’s environmental restoration needs and the human need to earn a living requires restoration managers to implement appropriate long-term measures that accomplish both goals. Only in this way is it possible for residents of ecologically fragile areas to escape the poverty trap (Cao et al., 2009). To be successful, ecological restoration must therefore be implemented by using an integrated approach, rather than by emphasizing only one of the two aspects.

Ecological degradation (including biodiversity loss) and poverty are linked problems that must be tackled together (Tallis et al., 2008). Our results clearly show that economic and social factors contributed strongly to the success of the ecological restoration program in Changtng County. For example (table 1), increased rural net income accounted for 12% to 24% of the increase in vegetation cover, decrease in soil erosion, and increase in species number, versus 14% to 23% for the area of fruit tree orchards. By improving livelihoods and increasing the income of poor residents, we were able to encourage them to adopt economic activities that would reduce damage to the environment, thereby increasing their enthusiasm for activities that led to ecological restoration. Because they have a strong incentive to participate in the new program, it becomes more likely that it will be possible to achieve the twin goals of improving livelihoods and protecting the environment in the long term.

Our results revealed that both objectives can be achieved when restoration managers eliminate the conflict between environmental protection and the needs of the poor. Policy makers must understand that residents of ecologically fragile areas need to survive and that their right to survival supersedes all other rights. Thus, for a development strategy to be effective and sustainable, it must eliminate poverty in the long term. Teaching farmers and entrepreneurs to create green enterprises that produce products from the land without causing ecological damage is an important component of ecological restoration (Biagini and Miller, 2013). In the present study, the role of the green enterprises can be seen in the programs to replace grazing of animals in degraded land with village-scale enterprises to raise livestock indoors and to use their manure to produce organic fertilizer; in addition to eliminating the damage caused by allowing these animals to graze in degraded land and giving that land a chance to recover, this approach provided manure that reduced the need to purchase expensive inorganic fertilizer. Similarly, the implementation of methane-generation facilities greatly reduced the need to harvest wood for cooking and heat. The green enterprises also encouraged regional governments to establish infrastructure such as roads to meet their own economic needs and accomplished other desirable goals such as preventing flooding or improving the efficiency of land use. Similarly, establishing or improving a transportation network can protect the soil against erosion (e.g. by converting a dirt road into a gravel or asphalt road) and can increase access to markets (London and Anupindi, 2012, Tompkins and Eakin, 2012). In the present study, increasing the length of roads significantly increased vegetation cover and significantly decreased soil erosion (table 1).

Eradication of poverty and ecological restoration are both important (Tallis et al., 2008). For farmers in ecologically fragile areas, environmental degradation and poverty reinforce each other to create the poverty trap; for example, the more land that is cultivated unsustainably, the greater the ecological damage, which in turn decreases crop yields and forces farmers to cultivate an even larger area of land to produce enough food to survive. By taking steps to eliminate poverty by providing better and more ecologically sustainable livelihoods for local residents, it becomes possible to protect the environment in the long term,
those compromises (Comim et al 2009). When the national or local government carries out ecological restoration projects, they must therefore fully account for the social and economic needs of those who are affected by the projects. Although they can provide an adequate allowance to compensate the people affected by the program, such subsidies tend to be short-term; in contrast, providing training, alternative forms of employment, and implementation support for such programs makes it possible to eliminate the need for ongoing subsidies because people can generate their own income (Gong et al 2012). If a project cannot provide a good ongoing livelihood for the local residents it affects, any claim to be promoting protection of the environment will be empty words, since the protection is likely to only be effective in the short term (Enfors 2013).

Although we did not explicitly study the effects of climate change in the present study, such changes will have important consequences that must be accounted for in regions that are experiencing significant impacts from global warming. Our results and those of previous researchers suggest that the key to successful ecological restoration is to harmonize beneficial ecological effects with beneficial social and economic changes (Reuveny 2008). When we perform ecological restoration projects, we must begin by understanding the local environmental conditions, how these conditions are changing, the economic conditions of local residents, and how these residents earn their livelihoods (Ginkel et al 2013). Planners can then consider how their proposals will affect and be affected by each of these factors. Sometimes achieving one goal will require compromises in other goals and a strategy to compensate anyone who is adversely affected by those compromises (Comim et al 2009). In addition, monitoring must be performed to learn the long-term effects on nature and society (Plagányi et al 2013, Stringer and Dougill 2013).

Although our results provide a model that can be adopted in many other regions of the world, it’s important to remember that natural and social factors differ greatly between regions. Thus, different factors will prove to be most important in different regions. For the approach described in this paper to prove effective in other regions, planners and restoration managers in each region must first identify the most important factors that they must account for in their planning.

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