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Targeted control measures for ecological restoration in Western Fujian, China

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A B S T R A C T

Ecosystem degradation is caused by interactions among multiple factors, including climate change and human activity. Therefore, we must understand the key factors that underlie ecological degradation and determine their impacts on ecosystem change before we can undertake ecological restoration. To test this hypothesis, we proposed a measure that we call "targeted measures to control ecological restoration". This approach calculates the contribution of every key factor and control measure to ecosystem change during ecological restoration; by identifying the key factors, it helps managers to design an effective restoration strategy based on those factors. To test this approach, we performed a case study from 2000 to 2016 in four towns of Changting County, Fujian Province, China. Although the vegetation cover decreased by 3.1% from 1984 to 1999, vegetation cover and vegetation species richness increased by 94.8 and 616.7%, respectively, in the test areas where new measures were implemented from 2000 to 2016. These rates were 4.5 and 148.2 times those in the control area, respectively. Our new approach focuses on repairing degraded ecosystems rather than creating new ones. The case study suggests that understanding ecosystem dynamics can help us deal more effectively with the simultaneous effects of climate change and human activity.

1. Introduction

Ecosystem degradation is causing major environmental issues around the world, including soil erosion and desertification (Sivakumar, 2007; D'Odorico et al., 2013). This degradation affects 36×10^6 km^2 globally, accounting for 25% of the world's land area and causing direct losses of up to 850×10^9 USD annually (D'Odorico et al., 2013). Ecosystem degradation is particularly serious in China, where 3.3×10^6 km^2 of degraded land accounts for one third of the total national land area; this affects more than 400 counties in 18 provinces, threatens the livelihoods of 400×10^6 people, and keeps 12×10^6 people in poverty, amounting to 28.5% of China's impoverished population (Wang et al., 2008). With ecosystem degradation becoming more serious and the area of arable land decreasing, poverty is also worsening (Olukoye and Kinyamario, 2009). Due to a lack of choices, residents in degraded areas are forced to engage in unsustainable activities such as deforestation, overgrazing, and land reclamation for agriculture, thereby exacerbating environmental degradation (Sietz et al., 2011). Because poverty leads to ecosystem degradation, and ecosystem degradation worsens poverty, this vicious circle is called the "poverty trap" (Cao et al., 2009; Kates and Dasgupta, 2007). It prevents sustainable socioeconomic development and threatens the long-term livelihoods of residents of affected areas (Tallis et al., 2008).

Ecosystem degradation results from interactions among multiple natural and human factors (Cao et al., 2014; Feng et al., 2015). Climate change and human activities both strongly affect vegetation change, and changes in vegetation communities in turn affect climate change (Shi et al., 2007; Ma et al., 2013) and human activities (Sun et al., 2012; Ma et al., 2014). Some natural sciences researchers suggest that climate change can degrade soil quality, vegetation cover, the species composition, and hydrological cycles, thereby resulting in ecosystem degradation (Marland et al., 2003; Zhou et al., 2009). At the same time, humanities researchers suggest that unsustainable human activities such as overgrazing, over-harvesting, and excessive groundwater exploitation create tremendous pressure on ecosystems, leading to degradation that accelerates soil erosion and other forms of ecosystem degradation (Zhao et al., 2005; Zheng et al., 2006). However, previous studies focused either on meteorological factors related to climate change (e.g., Sivakumar, 2007) or on anthropogenic factors related to human activities (e.g., Olukoye and Kinyamario, 2009). Few studies

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quantified the simultaneous effects of interactions among multiple factors, including both natural and human factors, based on long-term monitoring (Marland et al., 2003; Zhou et al., 2009). Because the approaches and data from the natural sciences and the humanities have not been combined, the research results provide a weak basis for environmental management, making it difficult to improve environmental protection.

Once an ecosystem has become sufficiently degraded that it requires ecological restoration, conditions are not conducive to the survival of most species. To solve this problem, traditional ecological restoration has focused on creating new ecosystems (e.g., when afforestation is chosen as the restoration option to create a forest that replaces the site's original grassland) with conditions that promote survival of the new species. Now, ecologists are increasingly recognizing the potential of rebuilding degraded ecosystems by taking advantage of natural mechanisms (e.g., biotic interference). However, the interactions between biotic factors and climate alter the results of environmental engineering by altering the underlying mechanisms responsible for ecosystem change (Suding et al., 2004; Lv et al., 2016). Because human activities can promote degradation, it's essential to understand the relationships between restoration mechanisms and socioeconomic development, thereby allowing more effective responses.

If we understand how natural and anthropogenic factors interact to produce a degraded ecosystem, we can manage those factors in ways that will help that ecosystem recover, thereby eliminating the need to create a completely new ecosystem. To do so, we must first identify the key factors responsible for degradation and recovery, and quantify their impacts on ecosystem change. Because unsustainable human activities are a primary cause of degradation, it's essential to identify their impacts so as to avoid activities that promote degradation processes and to encourage activities that promote recovery processes. The ecological restoration can only succeed when it simultaneously accounts for the ecological environment (e.g., climate, topography) and the production and living behaviors of residents of degraded areas. For example, it may be possible to develop green industries that both promote ecological restoration and improve livelihoods (Cao et al., 2017). This permits a win–win solution that combines ecological restoration with improved livelihoods. This approach should avoid the disadvantages of traditional projects, in which reclamation efforts targeted at impoverished people paradoxically make them poorer (Cao et al., 2017).

Unfortunately, ecological restoration in China and around the world still largely relies on a traditional approach that only focuses on ecological factors and ignores socioeconomic factors (Meli et al., 2017; Newmark et al., 2017). To improve the effectiveness of ecological restoration, it's necessary to move towards a newer, more holistic approach. In the present study, we hypothesized that taking advantage of natural restoration mechanisms while accounting for the factors that cause degradation could improve the effectiveness of restoration. We call this approach "targeted measures to control ecological restoration", and tested this method in a 16-year case study in China's Fujian Province. With targeted measures to control ecological restoration, researchers or project managers calculate the contribution of every key factor and every control measure to the mechanisms that underlie ecosystem change. Addressing each of these factors lets degraded ecosystems gradually recover to a healthy, stable state. This approach works by accounting for the coupling mechanisms among socioeconomic development, policy development, and ecological restoration (Meli et al., 2017).

2. Targeted measures and methods

2.1. Study area

Changting County is located in the western part of China's Fujian Province (between 116°00′45″E and 116°39′20″E and between 25°18′40′N and 26°02′05′N), and covers an area of 3.1×10^3 km^2. Annual precipitation averages 1730.4 mm. The annual temperature averages 18.3 °C (with an average minimum of 7.9 °C). In 2016, the county's population was 514.4×10^3 and its per capita income was 11 442 RMB (Cao et al., 2009).

Changting County historically had high vegetation cover. However, since the middle of the 20th century, government policy promoted forest harvesting and planting of monoculture forests. Paradoxically, this led to decreased vegetation cover, decreased biodiversity, severe soil erosion, frequent flood disasters, damage to the forest landscape, and other problems. There are many regions around the world similar to Changting County in terms of its severity of ecological degradation and its socioeconomic conditions, although the climate and geography may differ. The Brazilian rainforest region is one example (Escobal and Aldana, 2003). This part of Brazil had abundant ecological resources in the past, but Brazilians overexploited forest resources to encourage socioeconomic development, thereby causing severe ecosystem degradation in many areas. As a result, even though residents received short-term income from their activities, they remain impoverished because the ecosystems no longer support wood harvesting or other economic activities that could replace that harvest.

To prevent further land degradation, Changting County's government reformed property rights in the 1980s to make residents responsible for management of the forest. Under these reforms, 90% of the forest was distributed to farmers. Wood harvesting was required to follow the national wood harvesting policy, under which harvesting required the permission of the local forest administration. However, in contrast with expectations, poor residents of the county failed to consult the forest administration or learn how to protect their forest; instead, they sold the trees as fuel wood without permission and without any knowledge of sustainable harvesting techniques, leading to a rapid loss of forest cover and further aggravation of soil erosion and ecological degradation. The county's total area of soil erosion decreased from 974.6 km^2 in 1984 to 737.6 km^2 in 1999, but the area of severe soil erosion (> 8000 t km^{-2} yr^{-1}) doubled, from 55.8 km^2 to 113.2 km^2 (Table 1). The vegetation cover and forest cover both decreased by 3.1% and the number of vegetation species decreased by 11.1% during this period (Table 1). At the same time, despite the decreasing total area of soil erosion, ecosystem degradation remained serious in some areas (Zeng and Zhong, 2002; Cao et al., 2009).

2.2. New measures

Despite the serious soil erosion, this area was not included in China's national Grain for Green and natural forest protection projects. In 2000, Changting County's Soil and Water Conservation Bureau summarized its historical experiences and lessons, with the goal of implementing ecologically harmonious development of the county's economy and society rather than focused only on the environment. At that time, we provided advice on how to restore the natural ecosystems

Table 1
Changes in vegetation characteristics and soil erosion in Changting County from 1984 to 1999, before implementation of the new approach.

	1984	1999	Change (%)
Vegetation cover (%)	64	62	−3.13
Forest cover (%)	65	63	−3.08
Soil erosion area (km^2)	974.60	737.59	−24.32
Light soil erosion (< 2500 t km^{-2} yr^{-1})	594.73	478.65	−19.52
Moderate soil erosion (2500 to 5000 t km^{-2} yr^{-1})	207.13	58.93	−71.55
Heavy soil erosion (5000 to 8000 t km^{-2} yr^{-1})	117.13	86.85	−25.85
Severe soil erosion (> 8000 t km^{-2} yr^{-1})	55.80	113.16	102.80
Vegetation species			
Family (no.)	42	39	−7.14
Genus (no.)	64	57	−10.94
Species (no.)	81	72	−11.11