Greening China Naturally

Shixiong Cao[1*], Ge Sun[2], Zhiqiang Zhang[1], Liding Chen[3], Qi Feng[4], Bojie Fu[3], Steve McNulty[2], David Shankman[5], Jianwu Tang[6], Yanhui Wang[7], Xiaohua Wei[8]

1. College of Water and Soil Conservation, Beijing Forestry University, Beijing 100083, China
2. Southern Global Change Program, USDA Forest Service, Raleigh NC 27606, USA
3. Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 10085, China.
4. Cold and Arid Regions Environmental Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China
5. Department of Geography, University of Alabama, Tuscaloosa, Alabama 35487, USA.
6. The Ecosystems Center, Marine Biological Laboratory, 7 MBL St, Woods Hole, MA 02543, USA.
7. The Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing China.
8. Earth and Environmental Science Department, University of British Columbia Okanagan, Kelowna, British Columbia, Canada, V1V 1V7

*To whom correspondence should be addressed: shixiongcao@126.com (S. Cao)

Tel.: 86-10-6233-6324; Fax: 86-10-6233-8689

Abstract

China leads the world in afforestation, and is one of the few countries whose forested area is increasing. However, this massive ‘‘greening’’ effort has been less effective than expected; afforestation has sometimes produced unintended environmental, ecological, and socioeconomic consequences, and has failed to achieve the desired ecological benefits. Where afforestation has succeeded, the approach was tailored to local environmental conditions. Using the right plant species or species composition for the site and considering alternatives such as grassland restoration have been important success factors. To expand this success, government policy should shift from a forest-based approach to a results-based approach. In addition, long-term monitoring must be implemented to provide the data needed to develop a cost-effective, scientifically informed restoration policy.

Keywords

Afforestation policy _Environmental degradation _ Evironmental restoration _Reforestation _ Sustainable development

China is one of the few countries whose forested area is increasing. To alleviate severe soil erosion and desertification due to deforestation and overgrazing, China has implemented unprecedented large-scale afforestation throughout the country (Li 2004; Cao et al. 2011). From 2005 to 2010, more than 45 million ha of plantation forests and more than 20 million trees were planted (State Forestry Administration 2010). China’s forestry policies have focused on expanding forest areas and timber stocks by establishing plantations (Wang et al.

2008). However, this massive ‘‘greening’’ effort has been less effective than expected in some geographic regions. In some cases, the afforestation has produced unintended environmental and socioeconomic consequences, and has failed to achieve the desired ecological benefits (Cao et al. 2011). This article synthesizes the major factors that have affected China’s ecological restoration strategy, discusses the lessons learned, and offers perspectives for China’s future road to sustainability in forestry.

FAILING TO ACCOUNT FOR ENVIRONMENTAL AND VEGETATION CONDITIONS

Although China’s total forest area is increasing, monitoring suggests there have also been many planting failures that resulted from choosing inappropriate species (Cao et al. 2011). For example, the native vegetation in northern China’s arid and semi-arid regions usually comprises communities of small halophytic shrubs, steppe and savanna vegetation, and some herbaceous plants that grow on Aeolian sands and other soils vulnerable to wind erosion (Wang et al. 2010). In these regions, fast-growing exotic tree species (e.g., Populus tremula, Pinus tabulaeformis, Robinia pseudoacacia) have been preferred by Chinese foresters because they offer attractive short-term results, but the planted trees are often unsuitable for the afforestation sites in the long term; they deplete soil moisture because their transpiration rate is higher than that of the native plants they replace and higher than the rate at which soil water is replenished (Cao et al. 2011), thereby resulting in long-term soil desiccation and plantation mortality. This suggests that the first step to restore the degraded vegetation in arid and semi-arid China is to design an appropriate community structure by choosing the right species (i.e., species that have water requirements similar to or less than those of the original vegetation); where the water needs of a species under a region's environmental conditions are unknown, a more conservative approach based on restoring the original vegetation is more likely to succeed. For example, in areas where local managers restored natural grassland instead of planting trees, vegetation cover has improved and remained stable in the long term (Jiang et al. 2006).

Unfortunately, the reduced soil moisture and sunlight that develop under expanding tree canopies can lead to dramatic declines in the biodiversity and cover of native grasses and other plant species, particularly when planters remove some of this vegetation (whether manually or using herbicides) before planting to prevent it from interfering with tree establishment (Normile 2007; Cao et al. 2011). Planting trees may fail to control water and soil erosion in both arid and humid regions if understory vegetation is badly damaged, since this damage reduces protection of the soil surface, reduces infiltration of water (particularly when soil compaction develops), and can increase the erosive energy of raindrops as a result of the increased raindrop size that develops as canopy cover increases (Zhou and Wei 2002; Stone 2009; Wang and Cao 2011). Local residents describe the phenomenon as ''green mountains, but streams full of yellow mud''. Soil water and nutrient contents
may decrease or fail to improve after afforestation when surface flow dominates the hydrological processes because infiltration of rainwater is insufficiently rapid, carrying away nutrient-rich surface soils (Wang and Cao 2011). Large-scale studies also suggest that even where plantation-based soil conservation practices have significantly reduced sediment loads

in northern China, they have also reduced streamflow due to increased evapotranspiration (Sun et al. 2006; Zhang et al. 2008).

In China, only a small range of tree species have been used for afforestation of degraded lands despite the highly variable climatic conditions (Liu et al. 2008). In general, tree species have been selected mainly based on seedling availability, their initial ability to tolerate poor soils, and high growth rates capable of producing industrially useful wood (Stone 2009). High planting density has also been encouraged to quickly establish a high vegetation cover. Unfortunately, this ‘‘one size fits all’’ approach has had serious negative consequences. Between 1952 and 2005, overall survival rates of trees planted during reforestation projects have been as low as 24% for China as a whole (Cao et al. 2011). In addition, large areas were often dominated by a single species, leaving these monocultures susceptible to insect and disease problems (Li 2004; Stone 2009). Finally, there is a large difference between surviving and thriving. When trees are planted where they lack sufficient water or nutrient resources, they have low productivity and provide low levels of ecological services. For example, dwarfed trees have been observed throughout reforestation regions where annual precipitation was less than 400 mm (McVicar et al. 2010). These trees vividly illustrate the low growth rates and poor health that can result when trees are poorly suited to the local conditions.

GREENING CHINA NATURALLY

Historic vegetation patterns are a good guide for assessing suitable vegetation for reforestation (or grassland) restoration efforts. Therefore, species selection for revegetation should be location-specific, and not a ‘‘one size fits all’’ approach. We must therefore learn to observe and follow natural processes whenever possible when we design revegetation projects. Where we do not know the optimal species for local ecological conditions based on the results of long-term empirical research, nature’s own laboratory may provide the best available data. This will mean greatly expanding the species choices available to restoration managers.

In some cases, afforestation and planting may not be the optimal solution. Instead, the best strategy may be to protect a site from grazing and logging instead of planting trees (Sasaki et al. 2008). Theory suggests that a disproportionate loss of species occurs when vegetation cover decreases to between 10 and 30% (Lindenmayer et al. 2005; Radford et al. 2005). Jiang et al. (2006) provide suggestions about the characteristics that make a site suitable for a protection-based approach. To produce industrially useful wood, tree species with a high growth rate should only be planted in moist areas where the available water is greater than the physiological needs of the trees.

Many degraded ecosystems show remarkable ability to recover through natural processes (Mitchell and Ricardo 2004; Jiang et al. 2006; Cao et al. 2011). Thus, a key strategy for ecological restoration is to protect the natural soils and vegetation at a site and thereby take advantage of the ecosystem’s ability to self-repair; ecosystems have evolved over decades or centuries to use a site’s resources sustainably with little or no human intervention. However, natural recovery of degraded ecosystems can be difficult when they have crossed an ecological threshold and reached a new steady-state stage (Sasaki et al. 2008). Thus, research must be conducted to identify these thresholds, and managers must monitor ecosystems to determine when degradation thresholds are being approached.

In the low-fertility red soils of southern China, fertilization (and especially the use of organic matter to increase the soil's organic matter content) has assisted the recovery of natural vegetation, leading to successful ecological restoration (Changting County Government 2004; Cao et al. 2009). Unlike the use of herbicides, fertilizers and organic matter are attempts to supplement the natural rejuvenative power of nature, not supplant it. On low-fertility sites, it may be necessary to implement maintenance practices such as post-planting fertilization of the trees and other soil amendments (e.g., adding organic matter). The benefits of a ‘‘closer to nature’’ approach are many and varied, including a better mix of plant species, the development of richer humus, and an improved ability of the soil to retain water. As the vegetation begins to recover, it reduces surface runoff and stabilizes not only the hydrology of the watershed but also the local climate; this can lead to positive feedbacks in which the improved soil conditions accelerate vegetation recovery. In addition, the ecosystems are more resistant to pests and diseases both because they are more diverse and because supplemental fertilizer and organic matter increase the health and vigor of the trees (Stone 2009). The potential natural vegetation at any site depends on the local site conditions (climate, soils, and topography). Trying to determine the past, present, and future potential natural vegetation that these conditions can support is like a detective story, but this is an important mystery to solve.

To conserve ecosystem diversity and preserve native species and ecological services, it is sometimes more efficient to focus conservation funds on near-natural ecosystems; these may be less complex and diverse than true natural ecosystems, but so long as they are stable, they are a good compromise solution. Policies should be based on fundamental ecological restoration principles that emulate natural processes. Tradeoffs in ecosystem services that result from tree planting (e.g., increased wood production at the cost of decreased water availability) should be carefully considered before choosing afforestation (Jackson et al. 2005), and the choice must be based first on long-term stability. Managers must understand the tradeoffs among ecological and economic benefits, and between short-term and long-term benefits. Formulating a sustainable policy based on integrated solutions will also require policy developers and competing government departments to work together to avoid undermining any stakeholder's efforts (Guan et al. 2011).

Acknowledgments

This work was supported by the Fundamental Research Funds for the Central Universities (HJ2010-3) and the CAS/ SAFEA International Partnership Program for Creative Research Teams of ''Ecosystem Processes and Services''. We thank Geoffrey Hart (Montre´al, Canada) for editing an early version of this article.

REFERENCES

Cao, S., B. Zhong, H. Yue, H. Zeng, and J. Zeng. 2009. Development and testing of a sustainable environmental restoration policy on eradicating the poverty trap in China's Changting County. Proceedings of the National Academy of Sciences of the United States of America 106: 10712–10716.

Cao, S., C. Xu, L. Chen, D. Shankman, C. Wang, X. Wang, and H. Zhang. 2011. Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. Earth- Science Reviews 104: 240–245.

Changting County Government. 2004. Reaching out to combat soil erosion and construct a beautiful landscape of Changting County. Fujian Soil Water Conservation 16(4): 1–7. (in Chinese).

Guan, L., G. Sun, and S. Cao. 2011. China's bureaucracy hinders environmental recovery. AMBIO 40: 96–99.

Jackson, R.B., E.G. Jobbagy, R. Avissar, S.B. Roy, D.J. Barrett, C.W. Cook, K.A. Farley, D.C. le Maitre, B.A. McCarl, and B.C. Murray. 2005. Trading water for carbon with biological carbon sequestration. Science 310: 1944–1947.

Jiang, G., X. Han, and J. Wu. 2006. Restoration and management of the Inner Mongolia Grassland requires a sustainable strategy. AMBIO 35: 269–270.

Li, W. 2004. Degradation and restoration of forest ecosystems in China. Forest Ecology and Management 201: 33–41.

Lindenmayer, D.B., J. Fischer, and R.B. Cunningham. 2005. Native vegetation cover thresholds associated with species responses. Biological Conservation 124: 311–316.

Liu, J., S. Li, Z. Ouyang, C. Tam, and X. Chen. 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. Proceedings of the National Academy of Sciences of the United States of America 105: 9477–9482.

McVicar, T.R., T.G. Van Niel, L. Li, Z. Wen, Q. Yang, R. Li, and F. Jiao. 2010. Parsimoniously modelling perennial vegetation suitability and identifying priority areas to support China's revegetation program in the Loess Plateau: Matching model complexity to data availability. Forest Ecology and Management 259: 1277–1290.

Mitchell, A.T., and G.H. Ricardo. 2004. Globalization, migration, and Latin American ecosystems. Science 305: 1915–1916.

Normile, D. 2007. Getting at the roots of killer dust storms. Science 317: 314–316.

Radford, J.Q., A.F. Bennett, and G.J. Cheers. 2005. Landscape-level thresholds of habitat cover for woodland-dependent birds. Biological Conservation 124: 317–337.

Sasaki, T., T. Okayasu, U. Jamsran, and K. Takeuchi. 2008. Threshold changes in vegetation along a grazing gradient in Mongolian rangelands. Journal of Ecology 96: 145–154.

State Forestry Administration. 2010. China forestry yearbook. Beijing: China Forestry Press. (in Chinese).

Stone, R. 2009. Nursing China's ailing forests back to health. Science 325: 556–558.

Sun, G., G. Zhou, Z. Zhang, X. Wei, S.G. McNulty, and J.M. Vose. 2006. Potential water yield reduction due to reforestation across China. Journal of Hydrology 328: 548–558.

Wang, X., F. Chen, E. Hasi, and J. Li. 2008. Desertification in China: An assessment. Earth-Science Reviews 88: 188–206.

Wang, X., C. Zhang, E. Hasi, and Z. Dong. 2010. Has the three-Norths forest shelterbelt program solved the desertification and dust storm problems in arid and semiarid China? Journal of Arid Environments 74: 13–22.

Wang, Y., and S. Cao. 2011. Carbon sequestration may have negative impacts on ecosystem health. Environmental Science and Technology 45: 10.1021/es200042s htt://dx.doi.org/.

Zhang, X.P., L. Zhang, J. Zhao, P. Rustomji, and P. Hairsine. 2008. Responses of streamflow to changes in climate and land use/cover in the Loess Plateau, China. Water Resources Research 44: 1–12.

Zhou, G., and X. Wei. 2002. Impacts of eucalyptus (Eucalyptus exserta) plantation on soil erosion in Guangdong Province, Southern China—a kinetic energy approach. Catena 49: 231–251.