Viewpoint

Why Large-Scale Afforestation Efforts in China Have Failed To Solve the DESERTIFICATION PROBLEM

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Trenches were dug parallel to the contours during planting to prevent downslope erosion and collect slope runoff for the trees. The decreased vegetation cover can offset this advantage by increasing wind erosion.

Traditional Chinese approaches to ecosystem restoration have focused on afforestation as an important tool for controlling desertification. However, the long-term results of this practice increasingly show that these projects are actually increasing environmental degradation in arid and semiarid regions, with ecosystems deteriorating and wind erosion increasing. Rather than focusing solely on afforestation, it would be more effective to focus on re-creating natural ecosystems that are more suitable for local environments and that can thus provide a better chance of combating desertification.

Arid and semiarid regions make up ~40% of the earth's land surface and are home to ~20% of the human population, but these areas are increasingly being affected by desertification (*1*). A half-century policy of forest exploitation, livestock overgraz-

Planting trees in arid and semiarid regions of China has led to increased environmental degradation and impacts on soil moisture, hydrology, and vegetation coverage.

ing (*2*), and monoculture planting of forests (often to prioritize wood production) in China has led to the disappearance of many natural forests and to large increases in desertification (*3*). Currently, desertification is concentrated in the northwestern, northern, and northeastern parts of the country (the so-called Three Norths): an estimated 3.3 million km^2 have been affected by desertification, accounting for 34% of China's total land area (*4*).

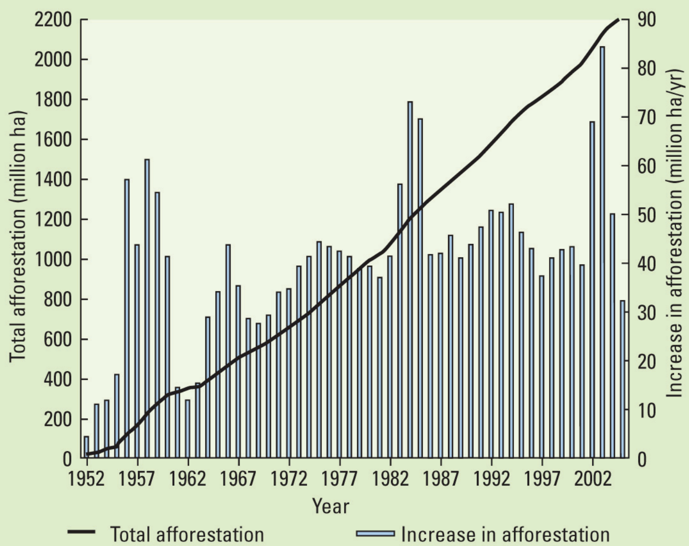
The Chinese government first recognized the problem of environmental degradation in these areas in the 1970s (*5*). As a result, since 1978 China has pursued one of the most ambitious conservation programs in the world—the Three Norths Shelter Forest System Project—to prevent desertification by carrying out large-scale afforestation in arid and semiarid areas (*6*). The project will continue until 2050 and will involve 551 counties in 13 provinces, covering a total area of 4.1 million km^2 (42.7% of China's land surface). In the project area, 30.6 million ha of afforestation is planned, at a cost of ¥4 billion ($1 ≈ ¥7.26 in January 2008). From 1978 to 2003, 23.5 million ha of grassland was planted with trees (*7*). To decrease the damage caused to Beijing by sandstorms created by desertification upwind of the city, the Taihang Mountains Afforestation Project in northern China, which began in 1999, will cover 110 counties in Beijing, Hebei, Henan, and Shanxi provinces, with plans to plant 3.6 million ha of forest (an investment of ¥50 billion from 1999 to 2010). From 1999 to 2005, 2.6 million ha of grassland was planted with trees (*8*). Another large-scale afforestation program, the Grain for Green Project, plans to spend an additional ¥300 billion to convert 147 million ha of farmland on steep slopes (≥25°) or with low yield and 173 million ha of grassland into forest in 25 Chinese provinces from 1999 to 2010 (*9*). By the end of 2003, 72 million ha of farmland and 79.3 million ha of grassland had been planted with trees under this project, covering >70% of the area of the Three Norths region (*10*).

In its scale, the number of participants, and the magnitude of the investment, China's afforestation project is the largest ecological restoration program in the world (*10–12*). China's government appears to be making aggressive changes in forest-related policies that formerly emphasized economic returns (*13*). Accordingly, the focus of the new policies is on how to grow more forests and how to shift from natural vegetation to planted forests. In this article, I evaluate potential links between environmental policy and environmental sustainability in China by presenting a historical perspective on Chinese afforestation projects. I provide a preliminary assessment of their impacts in terms of soil moisture, hydrology, and vegetation coverage.

FIGURE 1

Total area of afforestation in China from 1952 to 2005

Data from Ref. 8.



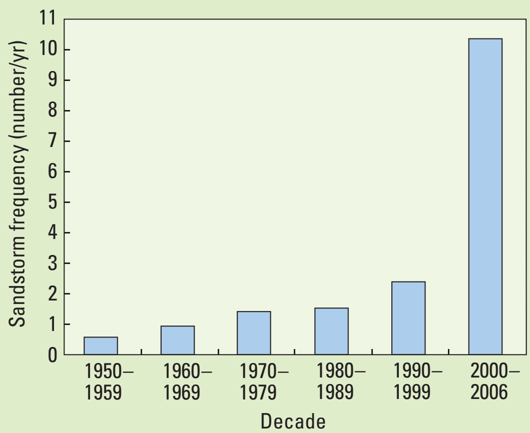
Failure of large-scale afforestation efforts

Although average annual precipitation increased and evapotranspiration decreased in response to warming of the climate of the Three Norths region from 1952 to 2005 (*14*, *15*), 29.1% of China's area (2.2 billion ha) was converted into forest by afforestation (Figure 1) (*8*). Although the area of afforestation is increasing rapidly as a result of the above-mentioned projects, the area of degraded land has continued to expand and the severity of desertification has continued to intensify throughout the country (*16*). This suggests that these costly efforts have yielded little success thus far; deserts in China have expanded to cover an additional 1560 km^2 of land every year from 1950 to 1975, 2100 km^2/yr from 1976 to 1988, and 3600 km^2/yr after 1998 (*4*, *15*, *17*). Accompanying this desertification, sandstorms have increased in frequency and intensity in recent years in northern China, from an average of 0.5 times per year in the 1950s to 10.3 times per year between 2000 and 2006 (Figure 2; *4*, *14–19*). The impact of these sandstorms is felt not only near the origins of the sand but also in eastern China and areas beyond, including Japan, South Korea, and North America (*10*). The economic and social costs of this land degradation and associated disasters have been enormous. Sandstorms are estimated to have caused more than ¥50 billion per year in damage since 2000 (*5*).

FIGURE 2

Sandstorm frequency in China since 1950

Data from Ref. 4 and Refs. 14–19.



Ignoring natural ecosystem characteristics

Drought is a major constraint worldwide to the production of common vegetation types such as forests (*20*), and revegetation of arid regions such as those in China is primarily water-limited (*21*). In arid and semiarid northern China, soil moisture is generally deficient in planted forests because of low annual precipitation, and this has led to large-scale mortality of plantations during drought years (*22*, *23*). Since 1949, the overall survival rate of trees planted during afforestation projects has been only 15% across arid and semiarid northern China (*9*). In abandoned agricultural areas that have undergone afforestation, most of the precipitation, and in some cases, all of the precipitation plus some of the soil's water reserve, is consumed by plant transpiration and evaporation from the soil surface (*24*). Previous research in these regions (*25*) has revealed that in contrast with natural grassland and forest, for which water use was historically in equilibrium with the water supply, soil moisture content to a depth of 6 m in afforestation areas had decreased by 32–37%. A clear inverse relationship exists between the soil's water balance and afforestation of grassland and farmland (*26*) because of the large amounts of soil moisture consumed by fast-growing trees. This moisture cannot be replenished during the rainy season; thus, reserves of soil water are depleted, the woody vegetation eventually dies because of water stress, and desertification ensues. Abundant data exist on the relationship between afforestation in northern China and decreasing soil moisture (*22–24*), and it seems reasonable that afforestation with inappropriate species will not produce a stable equilibrium with the available water supply.

China's implementation of large-scale afforestation throughout the country's arid and semiarid regions has ignored differences in topography, climate, and hydrology, all of which can affect tree survival. For example, wind abrasion of trees has been a significant problem. Wind speed averages 3–5 m/s in the Three Norths region and ranges from 4 to 6 m/s during the windy season from March to May; for 20–80 days per year, wind speed exceeds 5 m/s (the threshold for sand transport). As a result, 10–15% of newly planted trees were killed by windblown sand (*27*). In addition, water availability was insufficient to support trees in many regions. For example, the long-term mean precipitation of <200 mm/yr in arid regions is incapable of sustaining forest vegetation given the 2500–3000 mm/yr of potential evaporation common to these areas (*28*). As a result, natural ecosystems did not historically support extensive forests in these regions. The natural vegetation of much of the region was desert steppe vegetation or dryland shrub communities, which have a much higher water-use efficiency than most tree communities and which have evolved to use soil water sustainably under these environmental conditions.

To support wood production, which was an economic priority, >80% of the afforestation in the Three Norths region involved monoculture planting; often, fast-growing species with low water-use efficiency were used, such as *Populus tremula* L. (*7*). These monocultures typically consumed 20–40% more soil moisture than the steppe species that the trees replaced, leading to drying out of the soils, soil degradation, and greatly increased tree mortality (*29*). In addition, the water-stressed trees became increasingly vulnerable to plant diseases and insect pests (*7*). In total, 400 million ha of *P. tremula* monoculture was affected, and 15,000 ha/yr of plantations has died as a result of infestation by *Anoplophora glabripennis* Motsch. and *Anoplophora nobilis* Ganglbauer (two wood-boring beetles) in northern China (*30*).

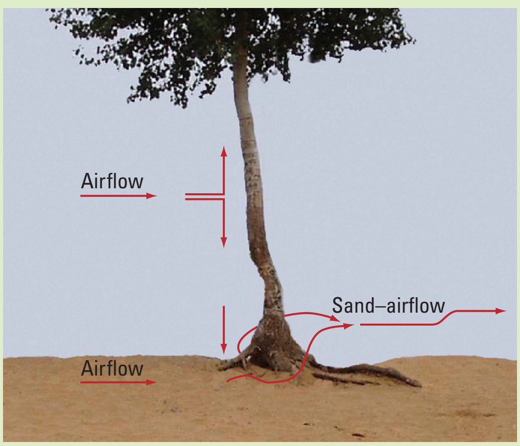
Adverse impact of afforestation on landscapes in arid areas

Vegetation cover. The above-mentioned decrease in soil moisture in afforestation plots, combined with reduced sunlight under the tree canopies (which adversely affects the growth of understory vegetation), has led to decreased vegetation cover in the afforestation plots. Net decreases of 30.5% occurred by the seventh year after trees were planted in grassland areas in northern China that had undergone afforestation; sometimes even entirely bare ground was produced (*25*). Because dense steppe vegetation can absorb more of the wind's momentum than less dense plant communities or bare soil, this vegetation can effectively control wind erosion (*31*). Regression analysis indicated that the rate of wind erosion decreased linearly with increasing plant density, aboveground biomass, and species richness. The rate of wind erosion was most strongly affected by vegetation cover, which accounted for 48.1% of the variation in erosion (*32*). These results suggest that the frequency of windblown sand would increase abruptly wherever the vegetation cover decreased as a result of afforestation (*33*). In addition, part of the airflow around sparsely forested areas is deflected downward by the trees and strikes the bare ground, increasing sand motion when airflow is blocked by the sparse trees during windy weather. This concentrates airflow at ground level (Figure 3), increasing the wind's erosive force (*27*) and generating larger sandstorms. Significant negative relationships were also found between the rate of wind erosion and soil moisture content, because moist soils are more cohesive and thus less vulnerable to wind (*34*).

FIGURE 3

Mechanism responsible for increased desertification

When an individual tree grows in arid or semiarid land in the absence of other vegetation to control sand movement, wind directed downward along the tree trunk strikes the bare ground and increases the entrainment of sand particles.



In the aforementioned study (*32*), soil moisture content exerted a strong influence on the rate of wind erosion, accounting for 13% of the variation in erosion. Last but not least, vegetation cover can significantly reduce the magnitude of erosion caused by surface runoff. Because large drops of water impart a significant force on the soil, and vegetation can slow the arrival of water at the soil surface to a rate closer to the soil's ability to absorb the water, interception of these drops by leaves can greatly reduce water-caused erosion. In contrast, with monoculture plantations, erosion by water can increase, particularly in comparison with grassland ecosystems, because of the reduced vegetation cover under the trees (*35*). Although certain management practices used during afforestation, such as trenches created parallel to topographic contours to intercept surface flow (photo on p 1826), can reduce water-caused erosion, the decreased vegetation cover can offset this advantage by increasing wind erosion. In one Chinese study, 70% of desertification was caused by wind erosion versus only 10% by water erosion (*36*). For these reasons, large-scale afforestation in arid and semiarid China appears to have been unable to control desertification and may actually be exacerbating the problem.

Hydrology. Many previous studies have reported that when the consumption of precipitation by tree plantations is higher than the level of consumption by natural vegetation, increased forest cover reduces the net runoff from a watershed (*21–25*). Previous research in northern China (*22*) revealed that the runoff from afforestation plots decreased by an average of 77% (ranging from 57 to 96%) compared with grassland and farmland. Although this decreased runoff suggests increased retention of precipitation and decreased water erosion, the retained moisture is often used more rapidly than it can be replenished during the rainy season. As a result, the trees actually decreased the belowground water supply and the supply of water to rivers (*25*), and any soil conservation achieved by the trees was subsequently offset by more severe wind erosion (*36*). Although the Chinese government has invested ¥40 billion in the South-to-North Water Transfer Project, designed to transfer 11.7 billion m^3 of water per year to mitigate water shortages in northern China (*10*), large-scale afforestation appears to be exacerbating the water shortage in northern China.

The groundwater reserve in any area has accumulated over historical periods and has generally reached equilibrium with the area's climate during periods of climatic stability. In arid regions, this water supply can sustain trees initially even when natural precipitation is inadequate to support forest vegetation. This is why many researchers have reported successful afforestation of large areas of desert. However, as afforestation expands and more trees begin growing in an area, the trees gradually deplete the groundwater to compensate for the inadequate precipitation. The effects of this depletion can be subtle at first, and as a result, people have been fooled by small-scale and short-term results into believing that desertification can be solved by large-scale afforestation. Unfortunately, the effects of increasing depletion of groundwater often become apparent many years later. For example, during the 1970s, the initially successful revegetation process used to stabilize mobile sands in part of the Mu Us Sandland served as a model for the rest of China, but 20 years later, >70% of the trees had died, and vegetation cover fell to even lower levels than before the afforestation as renewed desertification erased the early gains and soil moisture shortages were exacerbated (*37*). If policy makers are unwilling to adjust the current strategy, the afforestation projects not only will affect the present landscape but also will have adverse impacts on China's future environment.

Implications for practice

Although vegetation restoration is difficult, the creation of artificial ecosystems (i.e., forest plantations) that are inappropriate for their environment has caused the failure of this approach to combat desertification (*38*). However, desertification has been attributed primarily to human activities (*1*), especially to livestock grazing and farming (*2*, *5*), and secondarily to climatic changes (*39*). Therefore, we should certainly influence human activities, and doing so will be one key to reversing desertification: every ecosystem has a finite carrying capacity, and when that capacity is exceeded, degradation of the ecosystem occurs (*40*). However, ecosystems that are not damaged too badly show a remarkable ability to restore themselves rapidly and economically through natural processes (*41*), and this suggests that the key strategy to combat desertification will be to better understand the natural carrying capacity of each ecosystem and to use the ecosystem's resources sustainably to avoid damaging the ecosystem beyond its ability to self-repair.

Since 1949, the overall survival rate of trees planted during afforestation projects has been only 15% across arid and semiarid northern China.

In terms of revegetation strategies, planners must understand that different environments will support different vegetation communities and that forests are not a suitable choice in all areas. To successfully revegetate an area, planners must determine which vegetation types a given environment can naturally sustain and target restoration activities at creating such communities. For example, stable communities of natural desert steppe and grassland vegetation, and possibly even lichen species in more severely degraded environments, can develop in arid and semiarid areas as a result of natural processes, thereby increasing vegetation cover beyond the levels that could be sustained for trees, and can thereby provide better protection for the soil. The resulting communities exhibit decreased consumption of soil moisture, improved resistance to diseases and insect pests, and thus a greater ability to restore a stable ecosystem (*42*).

The observations above suggest that it would be more effective for the Chinese government to reduce its investment in afforestation and spend more on other proven strategies for controlling desertification. For example, the government should encourage the abandonment of farming in fragile and damaged areas and the removal of livestock from overgrazed areas, because such strategies have had large positive effects on vegetation cover, at less cost (*43*). To control desertification, China's government should also enlarge the Natural Forest Conservation Program (*6*), with the aim of banning further logging of natural forests and grazing in arid areas. Afforestation in arid and semiarid regions should be limited to the most mesic areas (*25*), with species such as dwarf shrubs chosen on the basis of maximum water-use efficiency rather than economic goals, such as the rapid production of wood fiber.

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Acknowledgment

I thank Geoffrey Hart for his help in writing this article.

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