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Conservation of natural and cultural heritage in Dunhuang, China

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ABSTRACT

A country's natural and cultural heritage is created in a unique environment, and for this heritage to survive, it must be preserved in a similar environment. In China, 60 years of afforestation to combat desertification near the Mogao Grottoes and the Crescent Moon Spring have shown that attempts to protect the regional environment have not protected these heritage sites, and may actually have endangered them. Conserving the environment's original state may be the most effective solution for heritage conservation where sites have survived under a specific set of physical and environmental conditions for hundreds or thousands of years and may not be able to survive a new environment. Man-made changes should only be attempted with great care to avoid damaging the conditions that have preserved the natural or cultural heritage in the long term.

1. Introduction

A nation's natural and cultural heritage represents both unique features of the natural environment and the products of human creative genius. Both bear testimony to cultural traditions, promote the development of modern civilization, and provide economic benefits such as tourism income (UNESCO, 2012). These artifacts are widely regarded as our world's most important treasures, and safeguarding these treasures has become a priority for both local and international organizations. For example, UNESCO continues to add new cultural and natural sites to its world heritage list, which now includes 745 sites (UNESCO, 2012), nearly half of which are in developing countries (Holden, 2003). Unfortunately, climate change, natural disasters, environmental degradation, and inappropriate management (Abbott, 2010) have created serious challenges for heritage conservation. Currently, only a small portion of the riches of our collective past has survived, and its survival is often jeopardized by unconstrained population growth. Other treasures are located in marginal sites with a fragile ecology that are at risk from human disasters such as pollution, uncontrolled urbanization, unconstrained tourism development, and armed conflicts, as well as natural disasters such as earthquakes (Abbott, 2001; UNESCO, 2012).

At the end of June 2011, 41 Chinese world heritage sites had been designated, of which 29 were cultural heritage sites, 8 were natural heritage sites, and 4 were sites of combined natural and cultural heritage; an additional 2348 locations were listed as Chinese state heritage sites (Anon., 2011). China's Dunhuang region provides two examples that provide lessons for conservators of other sites in China and around the world. As an example of cultural heritage, the Mogao Grottoes Mural System (Fig. 1, top) has been referred to as the "art gallery of the world" (Li et al., 2013). This system includes more than 750 caves, which contain approximately 45,000 m^2 of murals and more than 2500 painted sculptures (Fan, 2000) that were created between 25 and 945 A.D. As an example of a natural heritage, the Crescent Moon Spring (Fig. 1, bottom) is home to a classic image of a desert oasis that has survived centuries of sandstorms and mobile sands. The two sites attract more than 6 million visitors every year. Both sites have been threatened by desertification (Stone, 2008), as a protective measure against which, large areas of shrub and tree shelterbelt were planted in the 1950s and 1980s (Table 1). But while these efforts seemed wise at the time, some unintended negative impacts have begun to appear.

2. Research methods

The Mogao Grottoes (40°5′17.25″N, 94°40′16.67″E) and Crescent Moon Spring (40°5′11.98″N, 94°40′9.997″E) are located in Dunhuang County of China's western Gansu Province. The Mogao Grottoes contain murals and sculptures with unique artistic value (Li et al., 2013); as a result, they were listed as one of the State Priority Protected Sites by China's State Council in 1961, and were inscribed in the UNESCO World Heritage List in December 1987. In December 1991, the Crescent Moon Spring was listed as a National Key Scenic Attraction by China's

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Fig. 1. (Top) A representative image from the Mogao Grottoes Mural System. Shelterbelts have been planted around the Mogao Grottoes (middle) and the Crescent Moon Spring (bottom) in Dunhuang County, China, to provide protection against mobile sands.
Dexiang Gao supplied the top and bottom photographs.

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Table 1
Hydrological changes at the Crescent Moon Spring heritage site since 1955.

	Lake depth (m)	Lake area (ha)	Elevation of the dunes above the lake (m)	Area of the heritage site not buried by dunes (ha)
1955	9.60	1.67	105.97	19.49
1960	8.90	1.50	105.93	19.40
1965	8.10	1.47	105.94	19.41
1970	7.90	1.40	105.97	19.46
1975	7.60	1.33	105.86	19.50
1980	5.70	1.00	105.92	19.49
1985	2.05	0.57	105.94	19.43
1990	1.98	0.57	105.89	19.40
1995	1.67	0.55	105.75	19.32
1999	1.20	0.53	105.86	19.39
2000	0.86	0.50	105.91	19.41
2001	0.78	0.49	105.93	19.46
2002	0.94	0.51	105.97	19.49
2003	1.25	0.53	105.88	19.43
2004	0.92	0.51	105.76	19.40
2005	0.97	0.51	105.64	19.36
2006	0.90	0.50	105.56	19.30
2007	0.80	0.50	105.46	19.26
2008	1.80	0.84	105.39	19.18
2009	1.40	0.75	104.88	19.20
2010	1.20	0.72	104.33	19.08
2011	1.30	0.76	103.92	19.02
2012	1.40	0.78	103.53	19.03

Note: Data were provided by the management bureau of the heritage site.

State Council. To protect these two heritage sites against aeolian sand and desertification, 18,365 ha of shelterbelt (trees and shrubs) were established by local governments and the management departments responsible for these heritage sites in the 1950s, and more especially since the 1980s (Li et al., 2013).

To understand the impact of these shelterbelts on the climate in and around the caves of the Mogao Grottoes, a weather station was set up 100 m from the caves by a collaboration between the Dunhuang Cultural Research Institute and the Getty Historical Relics Protection Institute, and has been operated since 1989. Platinum 100-Ω thermocouples have been used to measure air temperatures, a polymer film hygrograph has been used to measure relative humidity, and a HOBO datalogger has been used to record both parameters near wall paintings in Grotto 53, Grotto 85, and Grotto 72. The range of the temperature sensor was −40 °C to 70 °C, with an accuracy of 0.2 °C over a range of 0 °C to 50 °C, and the resolution was 0.02 °C at 25 °C. For relative humidity, the operating range was 0% to 100%, with an accuracy of ±2.5% from 10% to 90% RH (to a maximum of ±3.5%) and a resolution of 0.03%.

To understand the seepage of irrigation water, we sampled the volumetric soil moisture content in the shelterbelt above the Mogao Grottoes at 10 points, spaced at 100-m intervals along the shelterbelt, during the growing season (May to September) in each year since 2000. Using a 10-mm-diameter soil auger, samples were obtained during the middle 10 days of each month at a depth ranging from 2.0 m to 2.5 m below the surface. Each sample was placed in a sealed steel box to retain its moisture until it could be weighed to determine its fresh weight; the samples were then oven-dried (24 h at 105 °C) to calculate the water content (a 1% difference in water content in the 50-cm^3 soil volume in the samples equals a change of 0.75 g assuming a mean bulk density of 1.5 g/cm^3 for the sand). These values were averaged to provide a mean value for the growing season. To understand the impact of the shelterbelts on the hydrology of the Crescent Moon Spring, we obtained statistics on the lake depth and area, the elevation of the highest dunes above the lake, and the area of the heritage site not buried by sand during the period from 1955 to 2012. This data was provided by the management department of Crescent Moon Spring.

We used regression analysis in the Statistical Package for the Social Sciences software (SPSS Inc., Chicago, IL) to appraise the impacts of the shelterbelts on relative humidity in and near the grottoes, and on the area of the Crescent Moon Spring site and the depth of its lake.

3. Results

The Dunhuang region is extremely arid. Dry rocky hills, mobile sand dunes, and gobi (gravel) deserts cover 86.8% of the total area (Qin et al., 2002). Monitoring data shows that the potential evapotranspiration reaches 3449 mm annually (Qin et al., 2002), versus an average annual

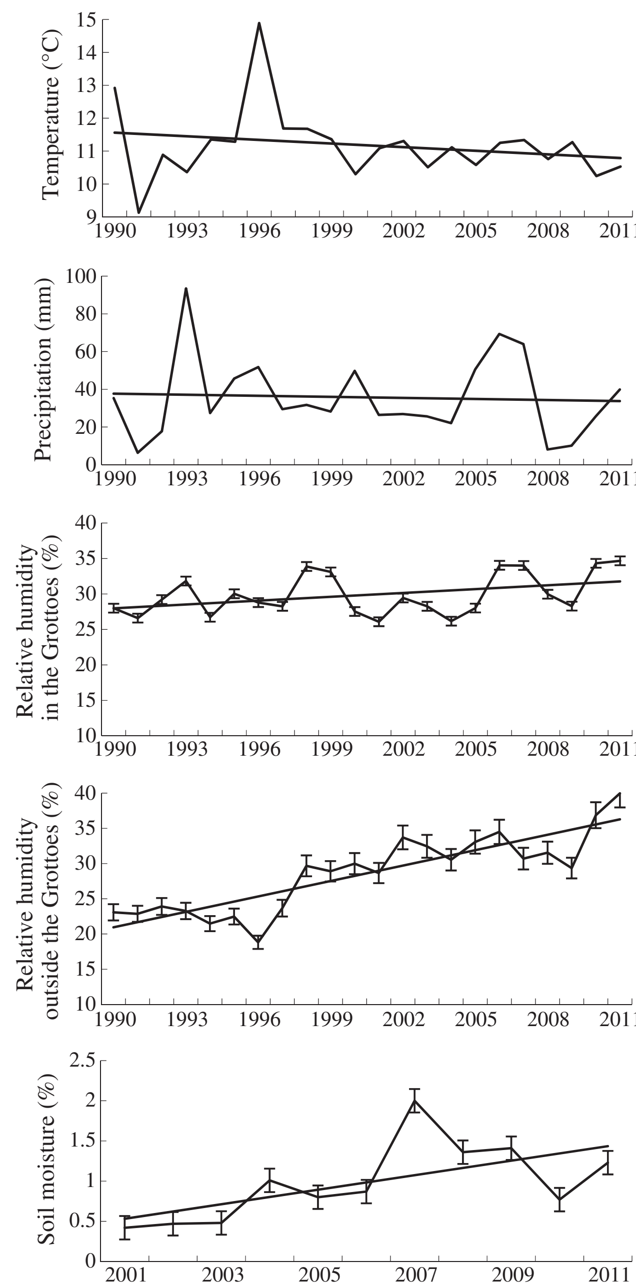

Fig. 2. Climate monitoring data for the two Dunhuang region heritage sites, and regression lines showing the trends since 1990. Meteorological data was provided by a weather station established at the site by the Dunhuang Cultural Research Institute and the Getty Historical Relics Protection Institute. Temperature represents the mean annual air temperature. Precipitation represents the mean annual precipitation at the two sites. Relative humidity is provided for both the grottoes and the region outside the grottoes. The soil moisture content was measured at a depth of 2.0 to 2.5 m at the grottoes. For relative humidity and soil moisture, values are the means ± SD (n = 36 and 50 measurements, respectively).

precipitation of 35.7 mm over the last 20 years (Fig. 2). To sustain the planted vegetation, underground water must be pumped to the shelterbelts around the heritage sites because there is insufficient precipitation and soil moisture to sustain the vegetation chosen for the shelterbelts. From May to September in a typical year, an estimated 8366 mm of water was used to irrigate the shelterbelts because of the huge potential evapotranspiration of the shrubs and trees, which is high even in comparison with the 2250 mm consumed for irrigation of farmland (Li, 2005, 2006). This irrigation has increased the soil moisture content as a result of infiltration, and has also increased the relative humidity of the air as a result of evaporation and transpiration by the vegetation. Monitoring has revealed that from 2001 to 2011, the soil moisture content at a depth ranging from 2.0 to 2.5 m in the shelterbelt above the grottoes and the relative humidity in the caves of the Mogao Grottoes have both increased significantly ($p < 0.05$) since 1990, by 193% for soil moisture (from 0.42% in 2001 to 1.23% in 2011) and by 24% for relative humidity (from 28.0% in 1990 to 34.7% in 2011), whereas the air temperature and precipitation have not changed significantly (Fig. 2). Regression analysis (Fig. 3) shows that the ambient relative humidity near the mural paintings has been significantly ($p < 0.05$) correlated with both the soil moisture in the ground near the Grottoes ($R^2 = 0.415$) and the relative humidity of the air near the Grottoes during the past 20 years ($R^2 = 0.486$). Although there is little direct evidence that irrigation water is infiltrating the Mogao Grottoes, damage has only been increasing during the period of irrigation, which is a time when regional precipitation and temperature have not changed significantly, and relative humidity has not changed greatly. This suggests that water infiltration through the highly porous sands of the study area is a likely suspect. Statistics provided by the administrator of the Grottoes suggest that the number of visitors per year averages to 478,000, and that each visitor spends an average of 5 to 10 min during their visit. Thus, the water produced by human breathing is another likely cause (Guo et al., 1999; Fan, 2000). In addition, the increased soil moisture and ambient relative humidity around the Grottoes will decrease the rate at which water vapor can escape from the caves. As a result, the relative humidity in the caves has been increasing steadily, leading to flaking, mildew, and other serious damage to the paintings (Guo et al., 1999), as well as moisture condensation and the precipitation of dissolved salts (Li, 2006; Li et al., 2013) (Fig. 4, top).

Pumping underground water to irrigate shelterbelts and farmland around the Crescent Moon Spring is also damaging this heritage site. Withdrawal of the water has led to drying of the site's lake, with the water depth decreasing from 9.60 m in 1955 to only 0.80 m in 2007 (Table 1). Although the management department responsible for this site has diverted water to replenish the lake since 2008, the water level and size of the lake remain far below their former levels. Because establishment of the shelterbelts around the two heritage sites has decreased wind speeds by 65 to 80% below the speeds upwind of the shelterbelts (Li et al., 2013), sand has begun accumulating in the shelterbelts, allowing the desert to approach both sites. The sand accumulation is creating a risk that both sites will be buried by sand because the wind is no longer strong enough to carry away the sand, and the sand that falls downward from the crests of the dunes cannot be moved back to the crests (Wang et al., 2004; Li et al., 2013). As a result, the dunes have moved an average of 0.84 m closer to the Crescent Moon Spring every year, decreasing the area of the site from 19.5 ha in 1955 to 19.0 ha in 2012 (Table 1). Regression analysis (Fig. 5) shows that

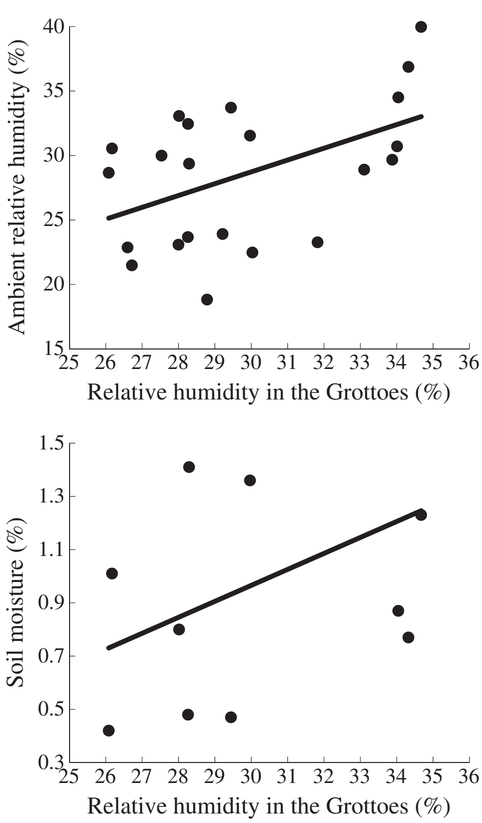

Fig. 3. Regression analysis for the relationship between relative humidity in the Mogao Grottoes and the ambient relative humidity near the grottoes (top), and the soil moisture at a depth of 2.0 to 2.5 m below the shelterbelt that was planted above the grottoes (bottom).

Fig. 4. (Top) The treasures at the Mogao Grottoes have begun to develop serious problems, including water seepage, flaking or cracking of the murals, salt precipitation, and shedding of the pigment layer. (Bottom) Burrowing by mice and other rodents is increasing in the shelterbelts, leading to erosion that is further threatening the grottoes.

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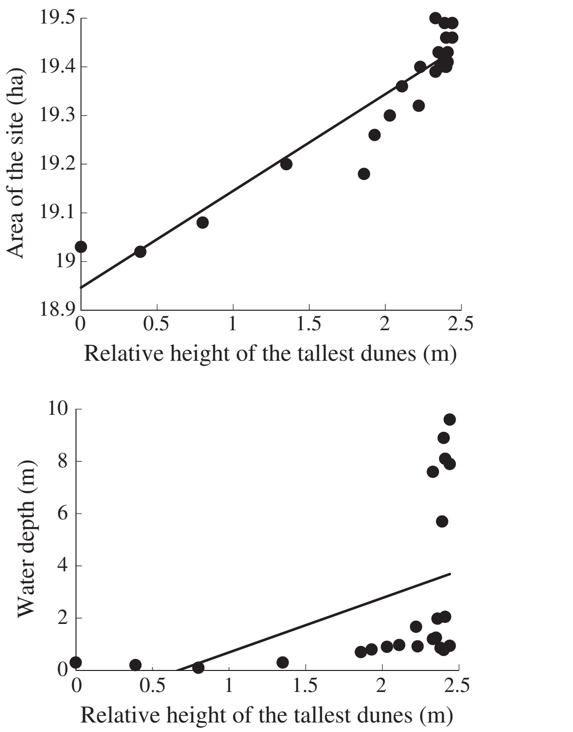

Fig. 5. Regression analysis of the relationship between (top) the relative height (the height in a given year minus the height in 2012) of the tallest dunes above the Crescent Moon Spring lake and the area of the site not covered by sand, and (bottom) the water depth in the lake.

the height of the eastern dunes (the highest dunes above the site) is significantly ($p < 0.05$) correlated with the depth of Crescent Moon Spring lake ($R^2 = 0.444$) and with the area of the site ($R^2 = 0.933$). Similarly, the dunes have moved an average of 2.81 m per year closer to the Mogao Grottoes since the afforestation began (Qu et al., 1997).

The vegetation that was intended to protect these sites has not only created the abovementioned problems; it has also increased populations of harmful insects such as *Apopestes spectrum* and *Autophila cataphanes*, of birds such as *Passer domesticus* and *Hirundo rustica*, of rodents such as mice (Fig. 4, bottom) and of species in the Microtinae (Wang et al., 2009). Because there are few natural enemies of these organisms in the simplified and fragile shelterbelt ecosystem, these organisms have invaded the heritage sites in search of food, including the straw that lies beneath the murals and that is a component of the sculptures. The actions of these organisms accelerate the flaking of the murals, stain the murals with their urine and feces, and physically damage the murals by burrowing or constructing nests (Wang et al., 2009). As a result, an estimated 93.7% of the murals and sculptures have been damaged by these organisms (W. Wang et al., 2005; Fig. 4, top).

4. Discussion

The natural and cultural heritage of the Dunhuang region has survived between 1600 and 2000 years because of the dry and windy local climate and a lack of human disturbance. In addition, long-term stability of the natural ecology before construction of the shelterbelts stabilized the dunes surrounding these sites. Unfortunately, the afforestation performed to protect these sites has greatly decreased wind speeds, reducing sand transportation away from the sites and increasing the risk that they will be buried by sand. The problem has been exacerbated by irrigation of the vegetation, leading to increased infiltration of water at the sites and increased humidity in the caves of the Mogao Grottoes, as well as decreasing water levels at the Crescent Moon Spring. Increasing populations of insects, birds, and rodents have further endangered the cultural treasures at these sites. Although the goals of the afforestation were laudable, the results have been unexpectedly negative. This problem adds to previous criticisms of the risks of large-scale afforestation to combat desertification in arid regions, which revealed problems such as depletion of groundwater, decreased vegetation cover, and decreased vegetation species richness (Cao et al., 2011; Wang et al., 2013). The unexpected damage caused by these efforts of protection will cause incalculable damage to heritage conservation efforts and sustainable socioeconomic development in this part of China, and similar problems may arise at comparable sites around the world.

Before interfering with an ecosystem that has been stable for centuries or millennia, we must remember that our actions are constrained by the ecosystem's response. Because ecosystems are complicated and are not completely understood (Ma et al., 2013), any ecological restoration practice should be rigorously examined to detect possible unexpected consequences. This care is important whether the goal is conservation of nature or conservation of our human heritage. Until the consequences of protection efforts are well understood, maintaining the status quo, while fixing smaller problems such as insect infestations within the heritage site, may be the most suitable approach. As the examples in this paper show, it is urgently necessary to strengthen research on how to best conserve our natural and cultural heritage, both in China and around the world.

5. Conclusions

A nation's natural and cultural heritage bears testimony to its cultural traditions, promotes the development of its modern civilization, and provides economic benefits such as tourism income. These artifacts are thus widely regarded as important treasures, and safeguarding these treasures has become a priority for both local and international organizations. In China, local governments have made great efforts to protect artifacts such as the Mogao Grottoes and the Crescent Moon Spring. Unfortunately, inappropriate management based on afforestation to create shelterbelts and irrigation to sustain the shelterbelts has failed to protect these heritage sites, and may actually have endangered them. Our study suggests that when natural and cultural heritage is created in a unique environment, it must be preserved in a similar environment. Conserving the environment's original state may therefore be the most effective solution for heritage conservation where sites have survived under a specific set of physical and environmental conditions for hundreds or thousands of years; they may be unable to survive a new environment. Man-made changes should only be attempted with great care and careful monitoring to avoid damaging the conditions that have preserved these heritages in the long term.

Disclosure statement

The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

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