MONTANA STATE UNIVERSITY

Sand dunes of the Darhat Valley Mongolia : understanding their origins, dynamics, and impacts on soils and vegetation

by Patrick Harold OConnell

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Resources and Environmental Sciences
Montana State University
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Abstract:
Nomadic pastoralism has endured for more than 1500 years in Mongolia. Within the last century political changes have affected pastoralism by altering traditional land use patterns. Erosion and sand dune activity in the Darhat Valley, Mongolia has accompanied the changes in pastoral practices over the last 50 years and has threatened the sustainability of rangelands hi some areas. The welfare of Mongolian herders is dependent on rangeland productivity. This study describes the affects of saltation and sand dune migration on soils and vegetation and determines if erosion was continuing in the Darhat Valley's Renchinlhumbe Sum. The New Spring Site (NSS) and the Hoogii Site (HS) were two Renchinlhumbe locations selected for this study.

As barchan sand dunes move they destroy vegetation leaving bare ground. If vegetation does not reestablish these areas, bare soils lose stability and erode. Because barchan dunes in Renchinlhumbe migrate 5-10 m annually, one can estimate the length of time since a dune has left an area. By measuring the thickness of the soil's A-horizon at increasing distances upwind from the base of windward dune slopes, continuing erosion could be estimated. The thickness of A-horizon along five transects upwind of five migrating dunes was measured. Vegetation data were also collected in this study. Plant community composition based on the percent cover of five data classes: 1) bare ground, 2) forbs, 3) grasses, 4) sedges, and 5) lichen was determined along seven transects. Each percent composition value was composited from three one-meter hoop measurements.

The thickness of A-horizon measurements showed progressing soil loss with increasing distances upwind of NSS dunes, indicating continuing erosion. Conversely, soil-loss and continuing erosion was not found at the HS. Soil stability at both sites was affected by compaction from large dunes and topography. The NSS had a gently rolling terrain and windward slope faces more directly exposed to scouring by saltation. The HS was predominately flat and less susceptible to scouring. Plant community composition data showed that forbs and grasses declined more slowly and recovered more quickly than sedges and lichen. Patterns of vegetative recovery were influenced by differing depths of sand accumulation, and accessibility to ground water.

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Nomadic pastoralism has endured for more than 1500 years in Mongolia. Within the last century political changes have affected pastoralism by altering traditional land use patterns. Erosion and sand dune activity in the Darhat Valley, Mongolia has accompanied the changes in pastoral practices over the last 50 years and has threatened the sustainability of rangelands in some areas. The welfare of Mongolian herders is dependent on rangeland productivity. This study describes the affects of saltation and sand dune migration on soils and vegetation and determines if erosion was continuing in the Darhat Valley's Renchinlhumbe Sum. The New Spring Site (NSS) and the Hoogii Site (HS) were two Renchinlhumbe locations selected for this study.

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CHAPTER 1

INTRODUCTION

Mongolia and Pastoralism

Mongolia is a landlocked country with 2.3 million people occupying 1.56 million km^2 (967,200 mi^2) between Russia (Central Siberia) and the People's Republic of China. Its latitude extends from 41 31 to 52 6 Northern Latitude (Hilbig, 1995). Mongolia contains five ecological zones: forest steppe (23%), steppe (27%), desert steppe (28%), Gobi desert (17%), and mountain (5%) (Graham and Baker, 1992). About one third of its population are herders of sheep, goats, cattle, yaks, horses, and camels. Fernandez (1999) asserts that half of Mongolia's population depends directly or indirectly on the pastoral economy.

Mongolia has a long history of nomadic pastoralism which dates back more than 1500 years. Prior to the 1900's, seasonal migration patterns tied to the ecology of Mongolian steppe ecosystems had been well established for over 700 years (Fernandez, 1999; Kotkin and Elleman, 1999). Within the last century political changes have affected nomadic herders by altering traditional land use patterns. In the 1920's Mongolia became a socialist country with a centrally planned economic system. The first major changes to affect pastoralism began in the 1940's with the beginning of livestock collectivization in Mongolia. By the early 1960's all herders and livestock had been consolidated into organized administrative units called sums. Each sum occupied a territory in which a group of herders worked collectively to manage and maintain the production of collective-owned livestock. In exchange, each herder in a collective received a salary and benefits (Fernandez, 1999). Collectives also developed mechanized infrastructures to transport trade goods, supplies, and medical and veterinary care to herders in the countryside.

Prior to the establishment of livestock collectives, animals were maintained in small herds by family units well distributed across the landscape. These herding households migrated seasonally and typically covered annual distances of 100-200 km (Agriteam Canada, 1997). Following collectivization, seasonal migrations continued, but the large collective herds meant higher intensities of grazing in areas previously occupied by the herds of just a few families.

Collectives were disbanded in the early 1990's following Mongolia's transition to a democracy, and pursuit of a free market economy. When this occurred the large livestock herds of the collectives were broken up and sold to individual herders, who now own their livestock outright. In this post-collective period, Mongolia has experienced a dramatic devaluation of its currency and herders have lost the government salaries and benefits they received (Kotkin and Elleman, 1999). As a result, contemporary pastoralists rarely exchange currency, but instead depend on the barter value of their livestock to purchase trade goods.

Because mechanized infrastructures were dissolved along with the collectives, herders must now travel to trade centers to purchase goods and access medical and veterinary care. To do so typically requires non-mechanized means, as few can afford to fuel or maintain a truck, and few can pay the inflated prices charged by middle men. It has, therefore, become impractical for herders to move far away from areas of trade to graze their livestock. Accordingly, pastoral migration patterns have changed dramatically in the post-collective period, and rarely exceed distances greater than 10-20 km from a trade center (Canada Agriteam, 1997).

The Darhat Valley

The Darhat Valley is located west of Lake Khovsgol in northern Mongolia. It is a large basin that was a lake system during the Pleistocene. Today, many small lakes and rivers characterize the basin and are all that remain of a lake comparable in area to Lake Khovsgol. The Darhat Valley is 110 km long and 10-40 km wide, and its floor is formed mostly in sandy-oozy lacustrine deposits and, more rarely, gravels (Golden and Tumurtogoo, 2000; Uflyand et. al., 1969). It supports a grassland community characteristic of the Mongolian steppe.

Renchinlhumbe Sum in the northern Darhat Valley represents one area in Mongolia where socioeconomic restructuring, and changing pastoral practices have significantly altered land use patterns. Renchinlhumbe has maintained a population of about 4000 people and 70,000 livestock through the 1990's (Tsagaan, 2000). Kotkin and Elleman (1999) report that 1724 residents were working-age adults in 1996, and of these 1207 (70%) made their living as livestock herders.

Over the last 50 years erosion and sand dunes have appeared, and subsequently spread in a number of Renchinlhumbe locations (Hoogii, 1999). As dunes have formed and moved across the landscape, they have destroyed vegetation in their path. In these areas forage productivity has been reduced, in some cases severely. Because the livelihoods of so many in Renchinlhumbe's post-collective community have come to depend directly on pastoralism, the loss of rangeland forage productivity has become a growing concern.

The overall objective of this project was to initiate the study of wind erosion and sand dune formation in Renchinlhumbe and develop a method for monitoring their progress. This will improve herders' awareness of these landscape processes and help them to make more informed land use decisions. Before these concerns can be addressed, however, an understanding of how and why sand dunes form, move, and impact soil surfaces is necessary. It is also beneficial to know about the implications of desertification in other areas of Asia.

Literature Review

The Physics of Sand Dune Migration

The primary components of soil are sand, silt, and clay. The smallest or finest fraction of these are the silts and clays with particle sizes between 0.05-0.002 mm and < 0.002 mm, respectively. Sand consists of particles between 0.05-2 mm. When soil is eroded by the wind, particles become suspended in air according to their respective particle sizes. If the wind is sufficiently strong, the silt and clay fractions of an eroding soil can be carried high into the atmosphere where they may remain suspended for days. These particles may travel hundreds of kilometers from their point of origin before returning to the ground (Lancaster, 1995).

Unlike silts and clays, most sands (i.e. particle sizes > 0.1 mm) are too heavy to travel long distances by wind. Instead, they tend to travel along the ground by a series of short bounces in a process known as saltation (Brady and Weil, 1999). Once a sand particle becomes airborne, it begins to accelerate as it falls back to the ground (Lancaster, 1995). This added momentum increases the particle's potential for dislodging other particles as it impacts the soil surface. The effect of saltation on soil is considered greatest on smooth, hard surfaces with little roughness[1]. Under these conditions, particles lose less momentum as they collide with the ground, allowing them to remain active longer, and to displace a larger number of stationary sand grains.

A single rebounding sand grain can dislodge as many as 10 stationary grains (Pye and Tsoar, 1990). A cloud of saltating sand therefore, can contribute significant scouring properties to the wind. Pye and Tsoar (1990) describe three erosional processes resulting from aeolian sands. Their list includes (a) *deflation* which refers to the loss of loose sediments by direct wind drag, (b) *entrainment*, the suspension of loose sediment by particle impacts, and (c) the *abrasion* of hard surfaces resulting from entrained clouds of sediment.

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[1] Surface roughness refers to the presence of vegetation or other non-erodible surface elements that impair the movement of sand across a surface (Lancaster 1995).

Though the study of sand dune dynamics is extensive, the process of dune accretion is still poorly understood. One theory proposed by Bagnold (1941) details a process driven by the tendency of loose sand to reduce the momentum of saltating sand grains. Saltating rapidly across smooth, hard, stable soil surfaces, they lose speed and energy when encountering the loose materials of an active sand bed. This causes the sand grains to fall out of suspension and accumulate, enhancing dune formation. Bagnold's theory, if correct, would explain how a dune can continue to receive additions and grow far downwind from a sand source.

Barchan Sand Dunes

The barchan is a crescentic sand dune characterized by a pair of wing/horn like structures extending downwind of its main body. According to Hesp and Hastings (1998), the barchan dune represents one of the most streamlined shapes in nature, and its wings/horns typify the streamlining effects of wind on a mobile, erodible surface. The formation of the wings/horns is attributed to the tendency of windblown sand to move more quickly along the sides of the dune than over its center where the impact angle is greatest (Pye and Tsoar, 1990). To maintain their crescentic form, barchans require a stable wind regime where a single, dominant wind direction persists. Pye and Tsoar (1990), and Lancaster (1995) further relate that these dunes are most stable in areas where sand sources are limited. Barchans which develop under these conditions have the potential to become long term landscape features that migrate great distances and endure for centuries. It is generally agreed that 5-10 m/yr is the typical migration rate for most large barchans, though rates >30 m/yr have been recorded for some smaller dunes (Gay, 1999; Khatelli and Gabriels, 1998; Lancaster, 1995). For a more detailed discussion of the dynamics of barchan formation see Pye and Tsoar (1990).

Desertification and Climate Change

Environmental data collected throughout the world over the last century provides compelling evidence of significant climate change within the last 100 years. Few regions provide more evidence of this than Asia, where desertification is an increasing problem for a rapidly expanding human population. Kazimierz (1980) contends that pollen spectra extracted from Upper Quaternary lacustrine deposits reveal that a shift towards aridisation began to occur throughout Siberia and central Asia about 2000 years ago. For at least 3000 years prior, these areas experienced a wetter, more humid climate regime (Kazimierz, 1980). Mongolian tree ring data indicate that, compared to earlier centuries, the 20th century represents a period of unusual warmth (Jacoby et al., 1996). In addition, Xue (1996) describes a trend towards aridity over the past 40 years for Mongolian and Inner Mongolian grasslands as evidenced by a significant southeastward shift of the mixed land use belt.

The extent to which anthropogenic activities have contributed to climate change has been a hotly debated topic for decades. Today, many scientists relate much of the change to an expanding human population and the changes in land uses that have been required to accommodate its growth. In support of this view Dahl and Mckell (1986) explain that of the 40,920 km^2 (66,000 mi^2) of Asian deserts which have been attributed to anthropogenic activities over the past 2500 years, 12,400 km^2 (20,000 mi^2) have formed within the last 50 years. The primary causes for the rapid expansion of Asian desertification during this time are attributed to deforestation, overgrazing, and over cultivation (Kharin, 1985; Xue, 1996).

CHAPTER 2

CHARACTERIZING WIND EROSION AND SAND DUNE ACTIVITY IN THE DARHAT VALLEY

Introduction

Decades of wind erosion and sand dune activity in the Darhat Valley's Renchinlhumbe Sum have resulted in the loss of productive rangeland. If Renchinlhumbe's pastoral traditions are to remain sustainable in the future, then its herding community will need to improve their understanding of the dynamic processes of wind erosion and sand dune formation. Currently, many areas affected by these processes are widely scattered throughout the Sum. This makes it difficult for herders to be sensible to how much total area in Renchinlhumbe has been impacted by wind erosion. Moreover, it makes it difficult for them to determine if effected areas as a whole are declining, remaining static, or continuing to spread over time.

To assess the need for implementing erosion control strategies, herders and government officials from the town of Renchinlhumbe (the Sum's trade center) wish to learn how to monitor areas impacted by wind erosion and sand dune activity to determine if these processes are ongoing. This will allow them to identify locations where wind erosion is continuing and grazing practices are in most need of evaluation and change. Though many effective monitoring techniques exist today, most are inapplicable in Renchinlhumbe because they require tools and technologies that are inaccessible to its pastoral community. Relative isolation, economic hardships, and severely limited natural resources necessitate the herders' need for simple, practical monitoring techniques.

Objectives

To assist Renchinlhumbe's pastoral community, the objective of this project was: (1) to characterize sand dune activity in the Darhat, and (2) to develop and test a simple monitoring technique capable of determining if erosion is continuing.

Methods and Materials

Site Descriptions

Two representative sites in the northern Darhat Valley were chosen for this project. Study area 1, the New Spring Site (NSS), was located (51° 13' 46.1726"N, 99° 37' 22.3366"E) approximately 12 km (7½ mi) north of Renchinlhumbe. This site occupied an area roughly 1 km^2 (0.62 mi^2) in size, and was situated between a stream at its westernmost boundary and a small wooded lake system at its northeast corner. The NSS features 6 barchan sand dunes which are migrating in a SE direction approximately 5-10 m per year (Figure 1). The landscape in this area is characterized by a gently rolling topography with some relatively steep slopes along the lake's shoreline. The general elevation for this site is 1560 m.

Study area 2, the Hoogii Site (HS), was established (51° 18' 20.6564"N, 99° 35' 10.90"E) approximately 25 km (15 ½ mi) NNW of Renchinlhumbe, and represents an estimated area of 0.75 km^2. This site borders a dry, eroded riverbed to its NW, which is believed to be the point source of the area's three barchan sand dunes (Figure 2). An escarpment approximately 150 m in front of Dune 1 determines the SE boundary for the HS. The dunes are traveling in a SW direction at an estimated 5-10 m per year (Hoogii, 1999). The HS is predominately flat between its NW and SW boundaries. The only exceptions to this were the dune trail ridges which formed as the dunes migrated.

The soils at the NSS and the HS were classified as fine-sandy, siliceous, Typic Calcicryolls. These soils are deep, well drained, and have high permeability. They are formed in lacustrine deposits which are extensive throughout the Darhat Valley. The climate is cold, with very cold winters, monsoonal summers, and fewer than seventy days of growing season annually. Based on precipitation and temperature data provided by the Renchinlhumbe Sum weather station for the twenty-five year period between 1974 and 1998, annual precipitation and temperatures in Renchinlhumbe typically range from 250 mm to 350 mm and -7.5 °C to -8.5 °C, respectively.

Study Design

Because barchans migrate 5-10 m annually, it is possible to estimate the length of time since a dune has left a particular area. If, as a dune migrates, reductions in the thickness of the soil surface (A-horizon) occur relative to increasing distance from the base of the dune's windward slope, then continuing erosion can be inferred. Based on this reasoning A-horizon thicknesses were measured along transects extending upwind from the windward base of 5 Renchinlhumbe sand dunes. Due to the mixing of soil horizons

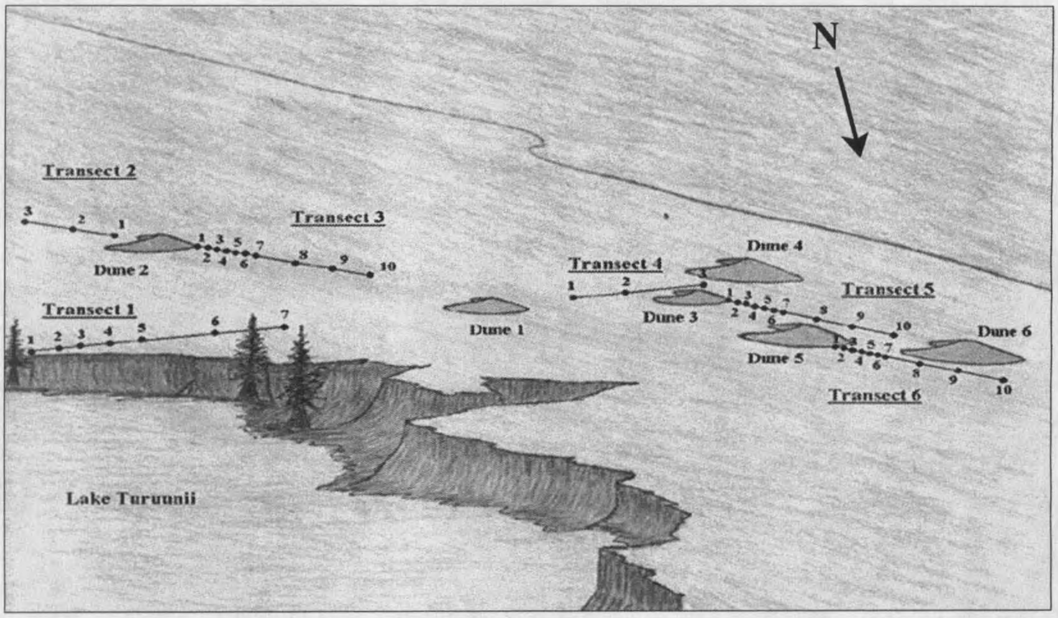

Figure 1. Illustration of the NSS with A-horizon thickness transects highlighted (not to scale).

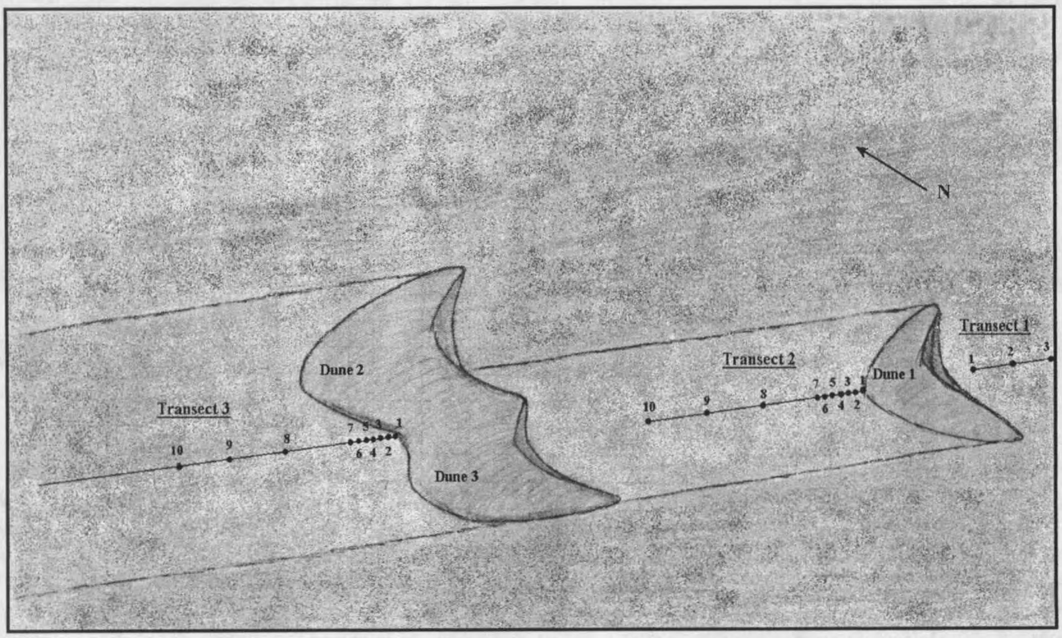

Figure 2. Illustration of the HS with A-horizon thickness transects highlighted (not to scale).

(possibly a result of freezing and thawing) accurate A-horizon thickness measurements could not be collected upwind of Dunes 1, 4, and 6.

A transect extending one hundred meters upwind from the base of a windward dune slope was established at three NSS and two HS sand dunes (Figures 1 and 2). Ten soil pits were excavated along each transect, and the thickness of A-horizon was measured for each pit. The first thirty meters of each transect contained soil pits 1-7 spaced at five meter intervals. Soil pits 8, 9, and 10 were positioned at fifty, seventy-five, and one hundred meters, respectively.

To establish a relative thickness for the A-horizon prior to dune impact and wind erosion, the thickness of A-horizon was measured at three positions downwind of each of two sand dunes. Extending seventy-five meters downwind from the base of the leeward slopes of the NSS Dune 2 and HS Dune 1, Transects 2 and 1, respectively, were established (Figures 1 and 2). A soil pit was excavated at 25 m, 50 m, and 75 m positions along each transect, and the thickness of A-horizon was measured at each.

For soil classification purposes, a soil profile description was completed for all NSS Transect 2 and HS Transect 1 soil pits. Similarly, complete profile descriptions were done at soil pits 8, 9, and 10 of HS Transects 2 and 3. Also, to complement vegetation data discussed in Chapter 3, profile descriptions were performed at NSS Transects 1, 2, and 4, and HS Transect 1. Profile horizon descriptors included: depth (cm), structure, texture, color, and effervescence (an indicator of carbonate presence). Textures were determined by using the hand texture or "feel method". Color was determined for moist