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Addressing desertification to achieve sustainable herding and grasslands

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ABSTRACT

The present review paper outlines a series of efforts to identify and solve desertification and wind erosion issues with the aim of creating sustainable drylands. These efforts incorporate the following three key projects under the Japan-Mongolia partnership that were funded by the Japan Society for the Promotion of Science (JSPS): “Integrating Dryland Disaster Science,” “Mongolian Herding Vision 2050 for Adaptation to Climate and Social Changes,” and “Regional Assessment of Desertification Using Bioaerosols: A Novel Method.” Regional focus is placed on the Eurasian grasslands, specifically Mongolia. This paper highlights the importance of (1) understanding the global history of desertification as a consequence of agriculture and climate change on a ten-thousand-year time scale, (2) assessing the irreversible nature of desertification using satellite remote sensing on a continental scale, and (3) monitoring the real-time change in wind erosion and soil fertility using bioaerosols on a regional scale. The combination of research from the above-mentioned spatial and temporal scales will help elucidate the dynamics of desertification, strengthening desertification risk governance with the goal of sustainable land management, and enhancing early warnings and early actions to avoid exceeding an irreversible threshold.

KEYWORDS

Land degradation, Grasslands, Herding, Bioaerosol, Mongolia

1. INTRODUCTION

A global assessment of land degradation indicated that Northeast China's grassland area is a hotspot of wind and water erosion resulting from decreased vegetation cover [1]. The most recent estimate of the proportion of Mongolia's area affected by desertification is 76.9%, with four defined degrees ranging from weak to very strong desertification [2].

Given that grasslands in eastern Eurasia have faced a growing threat of desertification, this issue has been addressed under a series of JSPS projects; "Integrating Dryland Disaster Science" (Project 1, [3]), "Mongolian Herding Vision 2050 for Adaptation to Climate and Social Changes" (Project 2), and "Regional Assessment of Desertification Using Bioaerosols: A Novel Method" (Project 3).

2. DEFINITION AND IRREVERSIBILITY OF DESERTIFICATION

The most widely accepted definition of desertification globally is provided in the United Nations Convention to Combat Desertification. Here, it is defined as land degradation in (climatologically defined) arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities [4]. While the above-mentioned definition of desertification does not encompass the concept of the timescales over which land degradation evolves and disappears, desertification is also defined as a temporary or permanent lowering of the productive capacity of land [5], which underscores its potential to be either reversible or irreversible. Irreversibility is a consideration in identifying hotspots within Asian grasslands using a novel NDVI-based indicator of the vulnerability vector (Project 1, [6]). Results have shown that some grasslands that cover sand dunes were the most vulnerable to drought disturbances. This implies that once grasslands were degraded by drought disturbances, the sand dunes that were stabilized by vegetation cover became mobile because of wind erosion, which was an irreversible process.

3. HISTORY OF DESERTIFICATION

The review paper [7] outlined the history of how various types of desertification/land degradation originated regionally, intensified, and spread to a larger area over the past hundred thousand years because of agricultural history and climate change. Region-specific agricultural methods that accommodate local natural resources have been developed in each of the major climate and vegetation types of the world (forest, woodland, and

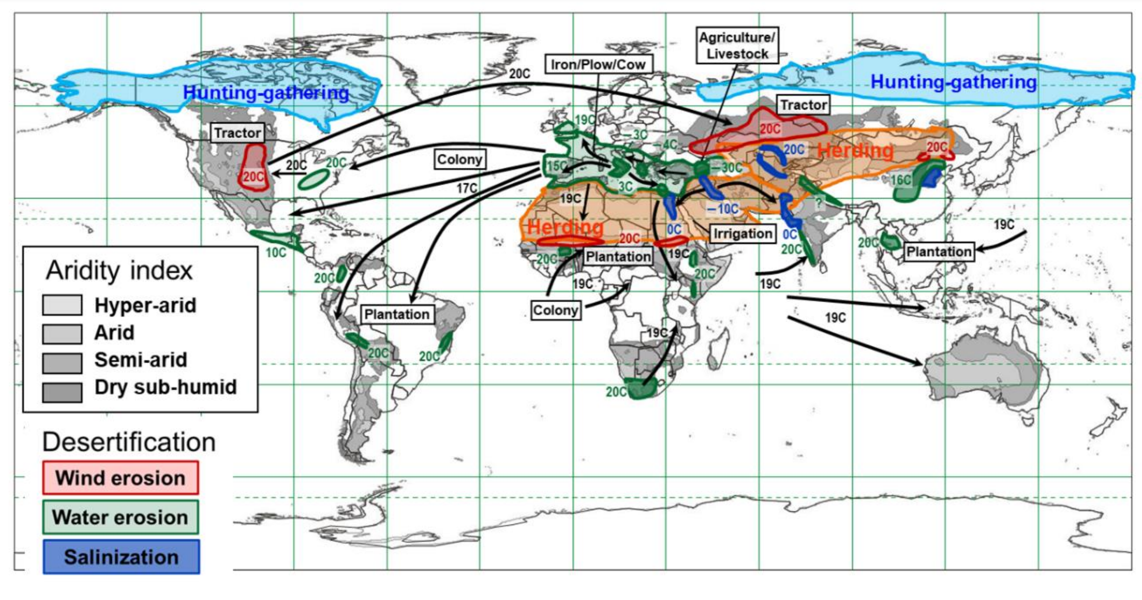

Figure 1. Propagation of farming methods and desertification [7]. Three desertification processes (or degrees of aridity) are shown by different colors (or in grayscale). Indigenous herding and hunting-gathering regions are also illustrated. Centuries in which very severe desertification took place are denoted by figures; negative values indicate centuries B.C. (before Christ). Corrections were made for three regions of West Asia and the Indus River [7]. Text labels denote desertification-inducing factors.

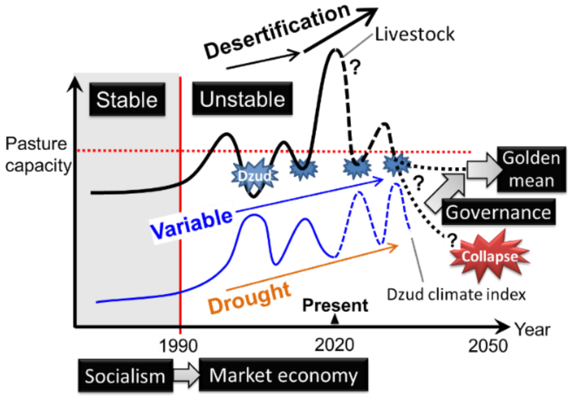

Figure 2. Required sustainable herding governance under the threat of desertification [9]. Livestock numbers are likely to exceed pasture capacity when driven by the market economy; numbers also vary annually in conjunction with dzud occurences.

grassland/desert), whereas the corresponding region-specific types of desertification have occurred where agricultural impacts exceeded the resilience of the natural resources. However, when particular agricultural methods were transferred to different climate and vegetation regions, desertification occurred because of the mismatch between agricultural methods and the new environment.

Agriculture is thought to have first been developed in West Asia approximately ten thousand years ago, and to have been subsequently transferred to Europe and America. This transfer was followed by the propagation of agriculture-derived water erosion (Fig. 1). Large parts of the Eurasian grasslands avoided this fatal land degradation, with the exception of limited areas that suffered from soil salinization or wind erosion. Therefore, in the central Eurasian grassland/desert region, nomadic pastoralism has survived for several thousand years, whereas the large-scale cereal and irrigated agriculture practiced under the Soviet Union regime led to region-specific types of desertification such as wind erosion and soil salinization, respectively.

4. IDENTIFYING THE THRESHOLD OF DESERTIFICATION

In recent decades, drylands in the Eurasian inland have been experiencing dramatic climatic and social changes; climatic changes include marked continental-scale warming and drying trends, while social changes include a regime shift from a planned to a market economy following the collapse of the Soviet Union in the early 1990s [8]. In Mongolia, nomadic pastoralism, which uses large areas of land in a dispersed manner in extreme environments with arid, cold climates, has been sustained for thousands of years, and is still one of the main industries. However, pastoralism faces a threat when the market economy leads to rapidly increasing animal numbers that may exceed pasture capacity, likely leading to desertification (vegetation degradation and wind erosion; Fig. 2) [9].

Given this context, Project 2 aimed to make an assessment of the ecological and socioeconomic sustainability of herding in Mongolia through the year 2050 using a newly developed, climate–ecosystem–society model. The project also proposes a vision of healthy herding to enable the society to realize both the ecological and socioeconomic sustainability that are measured using the pasture carrying capacity and consistent growth of the livestock-derived revenue, respectively. We identified several socioeconomic pathways with a livestock export boost policy that are vital to avoid overgrazing and to ensure the country’s

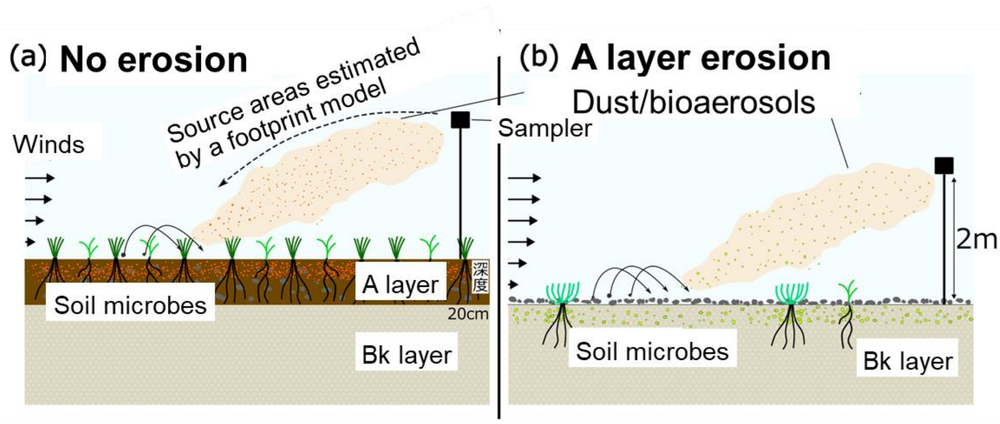

Figure 3. Wind erosion and bioaerosols. Plant species composition, soil profiles, and microbes are different between no erosion (a) and A layer eroded (b) conditions. Source areas of bioaerosols are estimated using a footprint model [13].

revenue stability. These scenarios have the potential to simultaneously realize the ecological and socioeconomic sustainability. In addition to the export boost policy, cooperative pasture management will help enhance both the sustainability [10].

5. BIOAEROSOL-BASED DESERTIFICATION/WIND EROSION MONITORING

Temperate grasslands deserve particular attention from aeolian researchers because they are subject to severe seasonal wind erosion that threatens ecosystem sustainability [11]. For this reason, we developed a new soil erodibility map across Mongolia in Project 1 [12]. The sustainability of this grassland ecosystem critically depends on interactions between climate change, grassland vegetation and human activities. Aeolian processes play a major role in these interactions. For example, overgrazing may result in decreased vegetation and increased wind erosion that constrains the recovery of grasslands during the subsequent growing season. Moreover, a marked drying trend in eastern Eurasia's arid region during the past century may have had an adverse impact roughly equivalent to that of overgrazing.

To detect the early signs of the desertification threshold and avoid surpassing it, we have proposed a novel method of assessing regional soil productivity and wind erosion based on bioaerosols (airborne bacteria and fungi; Fig. 3). We have conducted an ongoing bioaerosol investigation in the Gobi Desert since 2014 [14]. It should be noted that typical Mongolian steppes have a thin A layer of tens of centimeters, and that wind erosion can remove this layer in a short time while the timescale of soil formation is much longer. It is likely that the bioaerosols blown from the soil surface in different wind erosion stages (Fig. 3, No erosion vs. A layer eroded) have different microbial communities, which could be an efficient marker of desertification. In this study, MiSeq sequencing targeting ribosomal RNA genes is used to identify microbial community structures. We hypothesize that desertified landscape with the Bk layer exposed at the soil surface (the A layer eroded) tends to produce a drought- and salinity-tolerant airborne microbial community under a certain wind condition. The advantage of this method lies in the fact that the bioaerosol composition sampled at two meters above the ground reflects the composition for a larger spatial scale such as a one kilometer radius windward [13].

6. CONCLUSIONS

Desertification has occurred on a time scale of ten thousand years as agricultural impacts exceeded the resilience of natural resources. Additionally, the type of desertification differs globally depending on climate and vegetation types (forest, woodland, and grassland/desert). Nomadic pastoralism across the Eurasian grasslands is a unique livelihood that has survived for thousands of years in the grassland/desert region. For sustainable land management, this paper proposes new methods for monitoring desertification using satellite remote sensing on the continental scale and bioaerosols on the regional scale. Furthermore, the newly developed climate–ecosystem–society model will be an efficient tool for projecting near-future ecological and socioeconomic sustainability and proposing a desertification risk governance policy.

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