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Effects of vehicle track formation on soil seed banks in grasslands with different vegetation in the Mongolian steppe

Toshihiko Kinugasa*, Shozo Oda

Faculty of Agriculture, Tottori University, 4-101 Koyama-Minami, Tottori 680-8553, Japan

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ABSTRACT

Dirt road formation caused by the passage of off-road vehicles can lead to intense disturbances in underdeveloped regions. The natural recovery of vegetation after the abandonment of dirt roads depends largely on the soil seed banks, although the amount of damage to the seed bank composition, which determines the natural revegetation potential caused by dirt road formation, is unclear. We investigated the vertical distributions of seed banks in two grasslands in the Mongolian steppe with different above-ground vegetation, i.e., annual- and perennial-dominated grasslands, and we evaluated the effects of dirt road formation. The soil seed banks mostly comprised annual species of *Chenopodium*, irrespective of the above-ground vegetation, and the soil seed banks were larger in the annual grassland than in the perennial grassland. However, vehicle track formation removed the upper soil layers, which contained an abundance of buried seeds; therefore, the seed banks were small below the tracks, and almost the same size in the two grasslands. Our results suggest that natural revegetation through seedling emergence depends largely on annuals in the Mongolian steppe. Vehicle track formation damages seed banks severely; thus, artificial manipulations such as seeding or transplanting are required to facilitate the rapid revegetation of abandoned roads, irrespective of the above-ground vegetation.

1. Introduction

Soil seed banks are viable seed reserves, which are present in the soil and on its surface (Bakker et al., 1996; Roberts, 1981; Richter and Stromberg, 2005), and along with vegetative propagules they contribute to vegetation recovery after disturbances (Whittle et al., 1997; Kotanen, 1996). In particular, seed banks are essential sources of vegetation recovery, after intense disturbances involving soil removal, because vegetative propagules that are sometimes distributed in shallow soil layers are easily damaged. In fact, the contribution of seedling emergence to vegetation recovery after a disturbance increases with the intensity of the soil disturbance, whereas the contribution of sprouts from vegetative propagules decreases (Belsky, 1986). Thus, seed banks are good indices for estimating the recovery potential of grasslands after intense disturbance (Bekker et al., 1997), and evaluations of the effects of soil disturbance on seed banks may contribute to the construction of restoration policies and strategies after intense disturbance (cf. Ma et al., 2010).

The passage of off-road vehicles may cause intense disturbances in underdeveloped regions because they strip the vegetation, remove the surface soil and the seeds within it, and compact the soil (Hall, 1980; Lovich and Bainbridge, 1999; Webb, 1983). Soil compaction and vegetation loss induce wind and water erosion, resulting in further land degradation (Adams and Endo, 1980; Gillette and Adams, 1983; Hinckley et al., 1983). The natural vegetation recovery process after the cessation of dirt road use has been well described. In general, vegetation recovery on abandoned roads begins with the invasion of pioneer species, followed by colonization with short-lived perennials and then by long-lived perennials (Abella, 2010; Brown and Schoknecht, 2001; Prose et al., 1987; Webb et al., 1983). The recovery of the species composition or vegetation richness requires a longer period than that of the vegetation quantity, such as biomass and vegetation cover (Brodhead and Godfrey, 1977; Lovich and Bainbridge, 1999; Webb et al., 1983). The natural vegetation recovery process after dirt road abandonment has been well described, but there have been few studies of the amount of damage caused to seed banks by dirt road formation and the subsequent natural revegetation potential. Seeds are generally abundant near the soil surface (Guo et al., 1998; Luzuriaga et al., 2005; Warr et al., 1993); therefore, vehicle track formation will severely reduce the seed banks. However, soil compaction by

* Corresponding author. Tel.: +81 857 31 5384; fax: +81 857 31 5384.
E-mail address: kinugasa@muses.tottori-u.ac.jp (T. Kinugasa).

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vehicle passage presses down the seed banks; this may enrich the seed banks in the lower soil layer. In addition, wind-blown seeds are sometimes captured by depressions (Chambers, 2000; Brown and Schoknecht, 2001; Reichman, 1984), which means that vehicle tracks may capture seeds, thereby mitigating the damage to seed banks.

In the present study, we investigated the vertical distribution of seed banks in the Mongolian steppe and evaluated the effects of dirt road formation on the seed banks. Although the paved road network is still underdeveloped in Mongolia (only 2600 km of the total 49,500 km of the national intercity roads were paved in 2008; Keshkamat et al., 2012), the number of vehicles has increased steadily (on average by approximately 12% each year in the 2000s; National Statistical Office of Mongolia, 2003, 2007, 2011). Most dirt roads have multiple lanes because of random driving and passing (Li et al., 2006); therefore, the use of dirt roads is increasingly recognized as a cause of land degradation (Batjargal et al., 2006; Keshkamat et al., 2012). Vehicle passage has been reported to severely damage grassland vegetation in the Mongolian steppe. Natural vegetation recovery begins with the invasion of pioneer species, and the species diversity and vegetation cover increases during recovery (Li et al., 2006; Kinugasa et al., 2014). Evaluating the amount of damage caused to soil seed banks by vehicle track formation facilitates an estimation of the natural revegetation potential on tracks, which could contribute to the management of dirt roads after abandonment and the conservation of the Mongolian steppe. The majority of the Mongolian steppe is devoted to livestock grazing, which can alter the volume and composition of seed banks through changes in the above-ground vegetation (Hopfensperger, 2007; Kinloch and Friedel, 2005; Meissner and Facelli, 1999). Thus, we investigated seed banks in two grasslands with different grazing intensities: a grassland located close to a village that experienced relatively high grazing pressure, which was dominated by annuals; and the other grassland far from the village that experienced a relatively low grazing pressure, which was dominated by perennials. We addressed the following questions: (1) Do the species compositions and vertical distributions of seed banks differ in grasslands with different grazing intensities in the Mongolian steppe? (2) Does vehicle track formation affect the seed bank structure and the subsequent natural revegetation potential? (3) Does the effect of vehicle track formation on seed bank structures differ in grasslands with different grazing intensities?

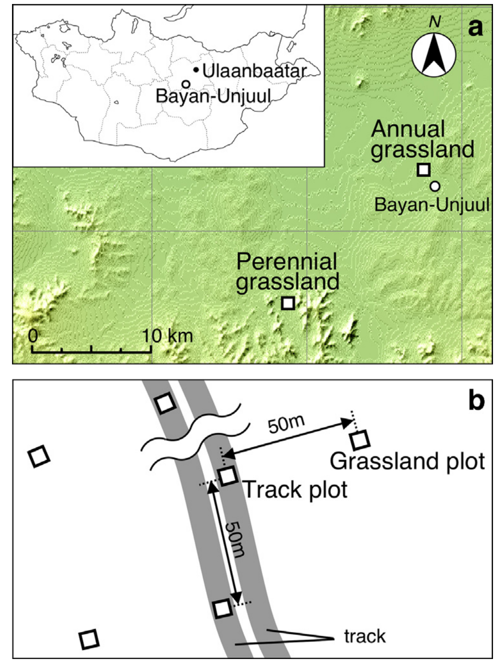

Fig. 1. (a) Location of the research sites (the annual grassland and perennial grassland) and (b) layout of the study plots measuring 50 cm × 50 cm (the grassland and track plots) in each research field.

2. Materials and methods

2.1. Study site

The research was performed on a dry steppe near Bayan–Unjuul village (47° 02.17′ N, 105° 57.33′ E), approximately 130 km southwest of Ulaanbaatar, which is the capital of Mongolia (Fig. 1). A meteorological monitoring station at Bayan–Unjuul (operated by the Institute of Meteorology and Hydrology of Mongolia) recorded an annual mean temperature and mean total precipitation during 1996–2010 of 0.4 °C and 159 mm, respectively. Local vegetation growth is generally initiated in May and ends in September, and approximately 85% of the annual precipitation occurs during that period. The monthly mean average temperatures during 1996–2010 were 11.6 °C, 17.9 °C, 20.8 °C, 18.0 °C, and 11.6 °C for the months of May–September, respectively.

In July 2011, two types of grasslands with different vegetation types were selected as the study plots (Fig. 1). The annual grassland was located approximately 1.5 km northwest of the center of Bayan–Unjuul (47° 02.84′ N, 105° 56.96′ E), and it was regularly grazed by large livestock herds dominated by goats and sheep, as well as horses and cattle. The annual grassland was dominated by annual species such as *Chenopodium album* and *Chenopodium aristatum* (Table 1). The perennial grassland was located approximately 15 km southwest of the center of Bayan–Unjuul (46° 56.69′ N, 105° 48.92′ E). According to local herders, the frequency of grazing by livestock herds in this area was low compared with that

Table 1
Percentage ground cover by each species in grassland and track plots in the annual and perennial grasslands.

	Annual grassland		Perennial grassland	
	Grassland	Track	Grassland	Track
	Ground cover (%)			
Annual species				
Bassia dasyphylla	–	<0.1	–	<0.1
Chenopodium acuminatum	3.1	<0.1	0.6	–
Chenopodium album	32.6	0.4	1.7	–
Chenopodium aristatum	28.0	0.7	0.3	–
Dontostemon integrifolius	0.1	–	–	0.3
Salsola collina	3.0	<0.1	<0.1	0.1
Annuals total	**66.8**	**1.3**	**2.7**	**0.5**
Perennial species				
Agropyron cristatum	<0.1	–	0.9	–
Agrostis sp.	<0.1	<0.1	–	–
Allium odorum	<0.1	–	2.7	–
Artemisia adamsii	3.7	<0.1	–	–
Artemisia frigida	1.4	–	20.3	0.3
Artemisia scoparia[a]	–	–	9.1	0.3
Astragalus galactites	0.2	–	–	–
Caragana stenophylla	1.4	<0.1	0.6	0.5
Carex spp.	6.6	1.2	7.4	6.3
Cleistogenes squarrosa	3.4	2.8	<0.1	–
Elymus chinensis	6.0	–	–	–
Haplophyllum dauricum	–	–	0.6	–
Potentilla multifida	0.1	–	–	–
Stipa krylovii	–	–	6.9	–
Perennials total	**23.0**	**4.2**	**48.6**	**7.4**
Grand total	**89.8**	**5.4**	**51.3**	**7.9**

The bold values show annuals total, perennials total, and sum of them (grand total). Headwords (Annual species and Perennial species) also are in bold letters.
[a] Biennial species.