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ORIGINAL PAPER

Colonization and expansion of grassland species after abandonment of dirt roads in the Mongolian steppe

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Abstract Off-road vehicles cause long-lasting damage to soils and vegetation, especially under extreme conditions such as those in arid regions. Most research on natural vegetation recovery after dirt-road abandonment has only investigated vegetation in the tracks and not that adjacent to the tracks. We investigated plant expansion into adjacent grassland after its colonization of abandoned tracks in the Mongolian steppe. We surveyed the vegetation around two roads: one abandoned for >4 years and another still in use near the abandoned road. Aboveground biomass and ground cover of each species in and beside the tracks were measured. The dirt roads had sustained relatively low vehicle traffic, so the disturbance of grassland productivity was limited. Vegetation cover and aboveground biomass had almost recovered 4 years after road abandonment. However, a low-palatability clonal herb, *Artemisia adamsii*, increased in abundance by producing many shoots in and around the abandoned tracks, thereby decreasing the quality of pasture. Our results show that vegetation recovery in tracks of the abandoned road can affect surrounding vegetation through the colonization and expansion of clonal species. Thus, to evaluate natural vegetation recovery after dirt-road abandonment, changes in vegetation not only within but also around abandoned tracks should be investigated.

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Introduction

Off-road vehicles cause long-lasting damage to soils and vegetation, especially under extreme conditions such as those of arid regions. The passage of off-road vehicles strips the vegetation, removes the surface soil and the seeds it contains, and compacts the soil (Hall 1980; Webb 1983; Lovich and Bainbridge 1999). Soil compaction and vegetation loss induce wind and water erosion, which cause further land degradation (Adams and Endo 1980; Gillette and Adams 1983; Hinckley et al. 1983). Vegetation recovery after cessation of dirt-road use has been well studied in arid regions. For example, natural vegetation recovery in abandoned roads starts with the invasion of pioneering species, followed by colonization by short-lived perennials and then by long-lived perennials (Webb et al. 1983; Prose et al. 1987; Brown and Schoknecht 2001; Abella 2010). The rate of vegetation recovery depends on the degree of soil compaction (Webb and Wilshire 1980; Payne et al. 1983), and the recovery of vegetation quality (e.g., species composition or richness) takes longer than that of quantity (e.g., biomass or vegetation cover) (Brodhead and Godfrey 1977; Webb et al. 1983; Lovich and Bainbridge 1999).

Most research on vegetation recovery after dirt-road abandonment has only investigated vegetation in the tracks and not that adjacent to the tracks. However, there is some evidence that plants that have colonized the abandoned tracks can expand outward and affect adjacent vegetation during the recovery process. Studies have shown that disturbed habitats are sometimes colonized by clonal plants that can rapidly expand in distribution (Walker and Chapin 1987;

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Waller 1988; van der Valk 1992). In a flooding grassland of Argentina, the clonal plant *Ambrosia tenuifolia* Spreng. rapidly spread out of colonized gaps and invaded 0.35 m^2 of the surrounding grassland within 120 days after gap opening (Insausti and Grimoldi 2006). Similarly, a 10-cm rhizome fragment of *Artemisia vulgaris* L. increased in length to 23 m in only 4 months (Barney and DiTommaso 2003). Thus, clonal ruderal species may colonize abandoned tracks and then quickly expand outside of the tracks.

The Mongolian steppe is part of the arid or semiarid grassland that covers much of northeastern Asia. In this region, the paved-road network is still underdeveloped, even though the number of vehicles has increased sharply. As a result, unpaved (dirt) roads have expanded in use and are increasingly recognized as a cause of land degradation (Asian Development Bank 2005; Batjargal et al. 2006; Keshkamat et al. 2012). Natural vegetation recovery in abandoned tracks within these roads has been studied little in the Mongolian steppe. We found only one such study (Li et al. 2006), by Li et al. (2006). It showed that species richness and vegetation cover in abandoned tracks had not recovered to the level of undisturbed native vegetation even 10–15 years after road abandonment, but they did not investigate the expansion of colonizing species outward from the tracks. In Mongolia, a rhizomatous perennial forb, *A. adamsii* Bess., colonizes degraded areas and is recognized as an indicator species for grassland degradation (Fernandez-Gimenez 2000; Fernandez-Gimenez and Allen-Diaz 2001; Yoshihara et al. 2010a). For example, the areas of bare soil produced by burrowing marmots are initially colonized by *A. adamsii* (van Staalduinen and Werger 2007; Yoshihara et al. 2010b). Thus, *A. adamsii* is likely to colonize abandoned tracks and expand outward into adjacent grassland in the Mongolian steppe.

In this study, we investigated vegetation expansion into adjacent grassland after plant colonization of abandoned tracks. We surveyed the vegetation in and around an abandoned dirt road and one that was still in use in the Mongolian steppe. We hypothesized that vegetation in abandoned tracks recovers naturally and that *A. adamsii* would colonize the abandoned tracks and quickly expand outward from the tracks. Because *A. adamsii* is unpalatable to livestock (Jigjidsuren and Johnson 2003; Damiran 2005), its colonization of disturbed sites and expansion may cause problems for animal husbandry, the key traditional industry in Mongolia.

Materials and methods

Study site

The study site, Bayan-Unjuul (47°02.67′ N, 105°56.97′ E), is located in a moderately dry steppe about 130 km southwest of Ulaanbaatar, the capital of Mongolia (Fig. 1). A meteorological monitoring station located approximately 800 m southeast of the study site (operated by the Institute of Meteorology and Hydrology of Mongolia) recorded an annual mean temperature and mean total precipitation from 1995 to 2010 of 0.4 °C and 159 mm, respectively. Annual precipitation during the study period was 162, 198, and 143 mm in 2008, 2009, and 2010, respectively. Growth of local vegetation usually begins in May and ends in September, and about 85 % of annual precipitation falls during that period. Monthly mean temperatures during the study period were 11.6, 18.0, 20.6, 17.2, and 11.9 °C for May–September, respectively. The study site is regularly grazed by large livestock herds dominated by goats and sheep, in addition to horses and cattle.

Potential dominant species in the study area are perennial grasses [*Agropyron cristatum* (L.) Gaertn., *Cleistogenes squarrosa* (Trin.) Keng, and *Stipa krylovii* Roshev.],

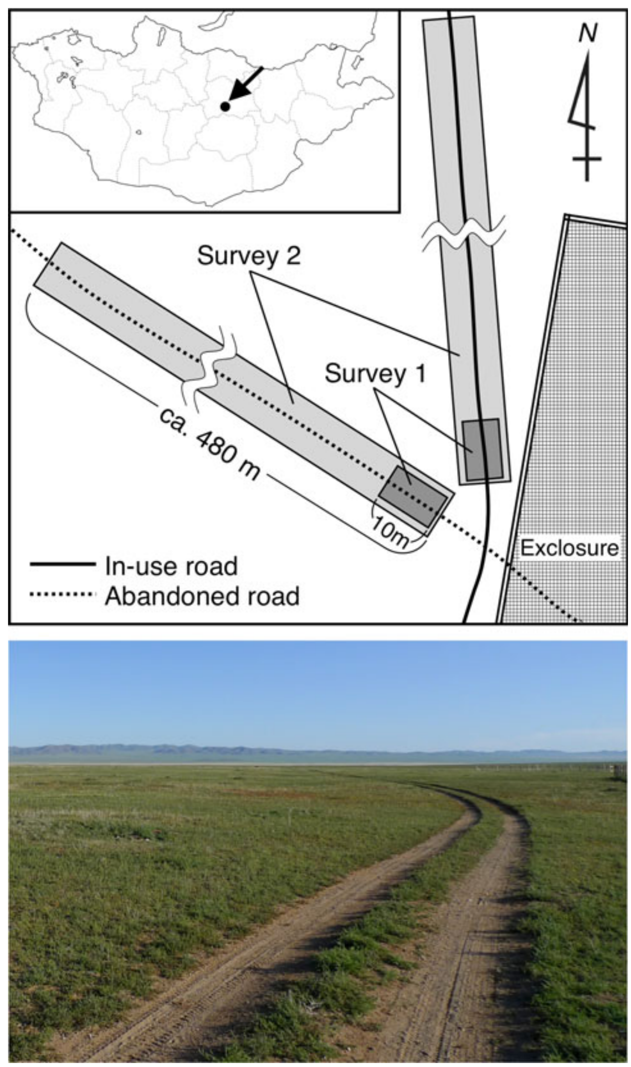

Fig. 1 Map of the roads surveyed in the study and a photograph of the in-use road in August 2009

perennial forbs (*A. adamsii*), and fabaceous shrubs such as *Caragana stenophylla* Pojark. (Nachinshonhor 2001). However, the study site experienced a severe drought in 2005, 2006, and 2007, and most of the vegetation disappeared (Kinugasa et al. 2012). The vegetation recovered in subsequent years with normal precipitation, and the dominant species during the study period were annuals such as *Chenopodium album* L., *C. acuminatum* Willd., *C. aristatum* L., and *Salsola collina* Pall. Soils at the study site are classified as Kastanozems and have a calcic horizon >40 cm below the surface.

We surveyed the vegetation around two dirt roads: one that was cut off by the construction of a grazing exclosure and abandoned in 2004, and one that was still in use near the abandoned road (Fig. 1). Thus, we expected that the vegetation around the roads would not have differed greatly when the two roads were in use. Because both roads are located outside of the exclosure, they were expected to be under the same grazing pressure. A maximum of five vehicles (primarily cars and motorcycles) passed along the in-use road during the daytime; the level of traffic at night is unknown but is expected to be low. The dirt road consisted of two tracks (a two-track jeep trail; Brooks and Lair 2005), and the width of each track at the study site averaged 75 cm. The road surface was created entirely by the passage of vehicles, with no grading or addition of materials to the surface (Fig. 1). As a result, significant amounts of vegetation remained in the center of the road between the tracks.

Survey 1

Vegetation surveys were carried out three times: in mid-July 2008, early September 2008, and late August 2009. In each road, we established line transects at a right angle to the road direction within a 10-m-long area along the roads (Fig. 1). Within each 10-m section of road, four transects were randomly established in July and September 2008, and three transects were established in August 2009. Intervals between transects were between 1 and 3 m. Along each transect, we established five 40 × 40-cm quadrats at 0, 70, 120, 260, and 400 cm from the track. The 0-cm plot was established at the center of one of the 75-cm-wide tracks. Vegetation cover was estimated visually using a 40 × 40-cm reference frame divided into 25 squares, each 8 × 8 cm. After estimating the vegetation cover in a quadrat, shoots of all plants in the quadrat were harvested and separated by species. The number of shoots of each species was recorded in July and September 2008. Harvested shoots were dried at 70 °C for >3 days and then weighed. Because of the destructive sampling, new transects were established on each survey date.

Survey 2

Because the study area in survey 1 was too small to ensure the generality of the survey results, survey 2 was performed in a wider area that extended ca. 480 m along the roads (Fig. 1). Within these areas, we established 20 transects for the in-use road and 25 for the abandoned road in 2010. Intervals between transects were 25 and 20 m for the in-use and abandoned roads, respectively. Line transects were established in the same manner as in survey 1. Quadrat size was enlarged, and the length of the line transect was extended from those in survey 1 to more accurately investigate vegetation and expansion of *A. adamsii* . Along each transect, five 50 × 50-cm quadrats were established at 0, 95, 175, 275, and 575 cm from the track. In each quadrat, the percent cover of total vegetation and that of *A. adamsii* were estimated visually using a 50 × 50-cm reference frame divided into 25 squares 10 × 10 cm each.

Soil hardness and water content

Ground-surface hardness was measured in each quadrat after the vegetation surveys in July 2008, September 2008, and August 2009. In each quadrat, we measured soil hardness using a soil hardness tester (PK-023, Fujiwara Scientific, Tokyo, Japan) at five points after removing the surface litter, and then averaged the results. Soil volumetric water content to a depth of 12 cm was measured at one point in each quadrat using a HydroSense soil moisture meter (Campbell Scientific Australia, Townsville, Australia) on 28 July and 10 September 2008. On both measurement dates, the 10-day precipitation prior to the measurement was <3.5 mm.

Statistical analysis

We tested for significant effects of road type and distance from the track on the aboveground biomass, vegetation cover, shoot number, shoot biomass, soil hardness, and soil water content by means of two-way analysis of variance (ANOVA), followed by the Tukey–Kramer post hoc test. Because transects were re-established randomly during each survey in survey 1, we treated data from different survey occasions as independent replications. All statistical tests were performed using the JMP 7 software (SAS Institute, Cary, NC, USA).

Results

Survey 1

Aboveground biomass was significantly affected by the type of road and distance from the track, and there was a

Table 1 Two-way analysis of variance (ANOVA) results (*F* values) for the effects of road type and distance from the track on the aboveground biomass and vegetation cover, and for three parameters of *Artemisia adamsii* (aboveground biomass, shoot number, and shoot mass) in survey 1

Source	*df*	Aboveground biomass	Vegetation cover	*Artemisia adamsii*		
				Aboveground biomass	Shoot number	Shoot biomass
Road (*R*)	1	9.31**	3.49 ns	45.21***	23.86***	3.47 ns
Distance (*D*)	4	2.58*	15.54***	5.30***	5.31***	0.57 ns
$R \times D$	4	7.45***	8.38***	3.90**	1.61 ns	1.05 ns
Error	100[a]					

ns not significant

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

[a] $df = 70$ for aboveground biomass and shoot number of *A. adamsii*, and 49 for shoot biomass of *A. adamsii*

significant road-type × distance interaction (Table 1). Aboveground biomass in and around the abandoned dirt road did not differ significantly among distances from the track (Fig. 2a). Aboveground biomass at the in-use dirt road did not differ significantly from that at the abandoned road, except in the track, where aboveground biomass was near zero at the in-use road.

Vegetation cover was significantly affected by distance from the track, and there was a significant road type × distance interaction (Table 1). Vegetation cover around the abandoned road did not differ among distances from the track (Fig. 2b). Vegetation cover at the in-use road was not different from that at the abandoned road except in the track, where vegetation cover was significantly lower than at this position in the abandoned road. Vegetation cover exceeded 35 % at both roads, except in the track at the in-use road.

Most of the aboveground biomass at the in-use road was accounted for by three annual species (*C. album*, *C. aristatum*, and *S. collina*), irrespective of the distance from the track (Fig. 3). *S. collina* accounted for at most 42 % of the aboveground biomass at the in-use road in 2008 but for >89 % in 2009. At the abandoned road, the aboveground biomass of the perennial herb *A. adamsii* was high in and around the track, especially in roadside areas adjacent to the track (70 cm from the track). The proportion of aboveground biomass for *A. adamsii* decreased with increasing distance from the track edge at the abandoned road on all three survey dates.

The aboveground biomass of *A. adamsii* was significantly affected by road type and distance from the track, and there was a significant road type × distance interaction (Table 1). At the in-use road, the aboveground biomass of *A. adamsii* was small, irrespective of the distance from the track (Fig. 4a). The aboveground biomass of *A. adamsii* was significantly larger at the abandoned road than at the in-use road both at and near the roadside (70 and 120 cm from the track). The number of shoots of *A. adamsii* was significantly affected by road type and distance from the track (Table 1) and was significantly higher at the abandoned road than at the in-use road at the roadside, 70 cm from the track (Fig. 4b), but there was no significant road type × distance interaction. Shoot biomass of *A. adamsii*

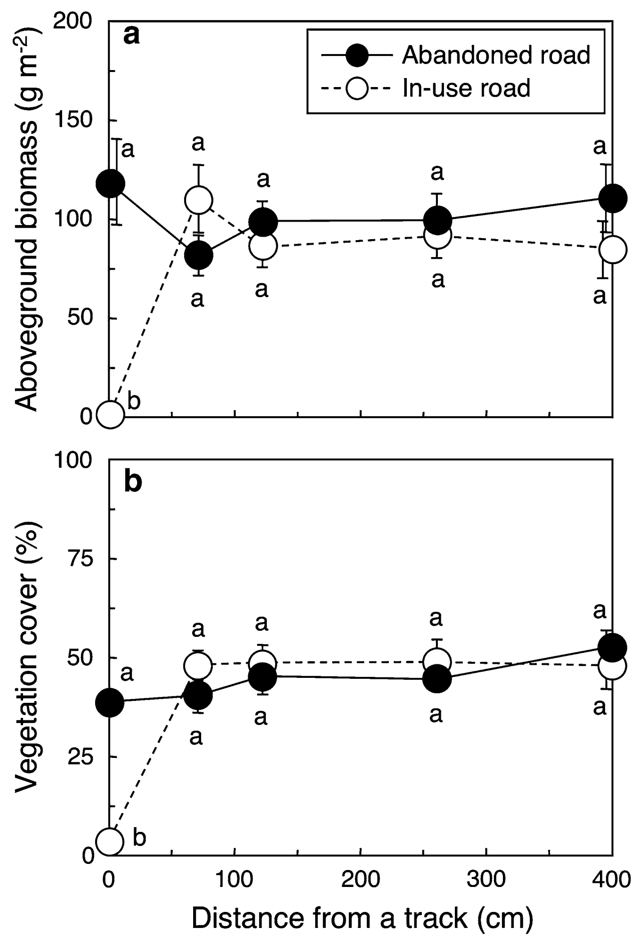

Fig. 2 **a** Aboveground biomass and **b** vegetation cover in and around the road tracks in survey 1. Data were pooled over survey occasions (July 2008, September 2008, and August 2009). *Symbols labeled with different lowercase letters* differ significantly among distances and road types (Tukey–Kramer test; $P < 0.05$). *Error bars* represent ±1 standard error ($n = 11$)

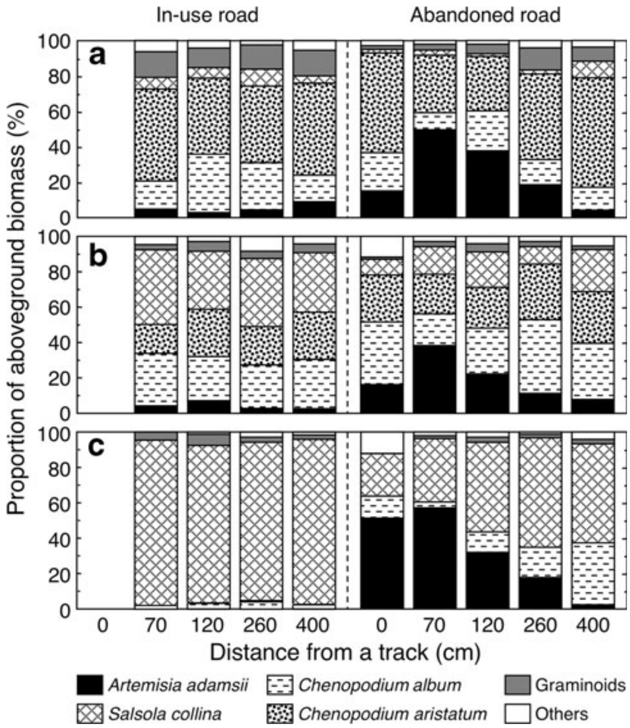

Fig. 3 Relative biomass composition by the dominant species or species groups in and around the track for the in-use dirt road and the abandoned road in survey 1: **a** July 2008, **b** September 2008, and **c** August 2009. Because the aboveground biomass in the track in the in-use road was nearly zero, we did not calculate the relative biomass composition for this position

did not differ significantly between road types or among distances from the track, and there was no significant interaction (Table 1) because of its high variation within each plot (Fig. 4c).

Survey 2

Vegetation cover was significantly affected by road type and distance from the track, and there was a significant road type × distance interaction (two-way ANOVA, $P < 0.05$). Vegetation cover in the track of the in-use road was zero and was significantly lower than in any other plots at both roads (Table 2). At the abandoned road, the vegetation cover in the track was significantly lower than in the other plots. Vegetation cover, except in the tracks, did not differ significantly between the two roads. The proportion of *A. adamsii* in the vegetation cover was significantly higher in the track and at the roadside (95 cm from the track) at the abandoned road than in any other plots at either road (Table 2).

Soil hardness and water content

Ground-surface hardness was significantly affected by road type and distance from the track, and there were significant

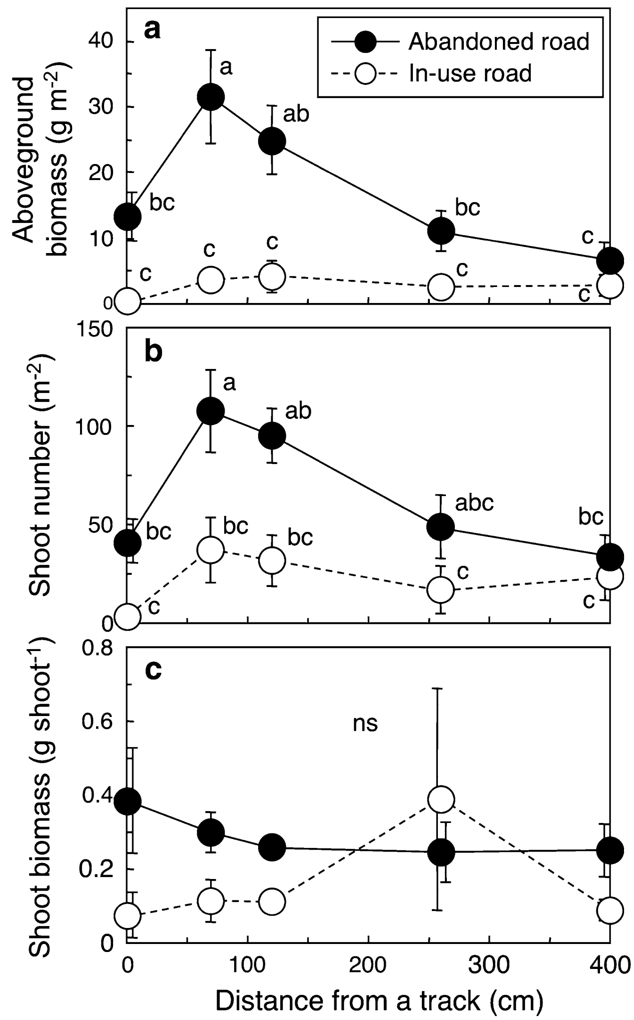

Fig. 4 **a** Aboveground biomass, **b** number of shoots, and **c** shoot biomass of *Artemisia adamsii* in survey 1. Data were pooled over survey dates (July 2008 and September 2008). *Symbols labeled with different lowercase letters* differ significantly among distances and road types (Tukey–Kramer test; $P < 0.05$). *Error bars* represent ±1 standard error ($n = 8$ for aboveground biomass and shoot number, $n = 2$–6 for shoot biomass)

distance × road-type interactions (two-way ANOVA, $P < 0.05$). Ground-surface hardness was significantly higher within the track at the in-use road than in any other plots at both roads but did not differ significantly between roads and among distances at any other position (Table 3). Although soil water content to a depth of 12 cm was measured on two dates, results did not differ between measurement dates, and no interactive effects of measurement date were found (three-way ANOVA using date, distance, and road type as factors). The 10-day precipitation prior to the measurement was <3.5 mm on both dates, indicating that soil was similarly dry on those dates. Despite the dry conditions, soil volumetric water content was significantly higher within the track at the in-use road than at any other distance for both road types (Table 3).

Table 2 Vegetation cover and its proportion of *Artemisia adamsii* in survey 2

	Distance from the track (cm)				
	0	95	175	275	575
Vegetation cover (%)					
In-use road	0^a (–)	39.0^c (2.09)	37.8^c (2.03)	35.8^c (1.96)	39.0^c (1.68)
Abandoned road	27.2^b (1.53)	36.9^c (1.89)	40.2^c (1.82)	43.3^c (1.51)	42.0^c (1.77)
Proportion of *A. adamsii* in the vegetation cover (%)					
In-use road	– (–)	11.1^b (4.67)	11.5^b (5.03)	12.9^b (4.75)	12.5^b (3.21)
Abandoned road	54.5^a (6.63)	53.1^a (6.27)	25.3^b (3.80)	25.0^b (4.82)	15.7^b (3.58)

Values labeled with different superscript lowercase letters differ significantly among distances and road types (Tukey–Kramer test; $P < 0.05$). Values in parentheses represent ±1 standard error ($n = 20$ for the in-use road, $n = 25$ for the abandoned road)

Table 3 Ground hardness and soil volumetric water content to a depth of 12 cm in and around the track measured in survey 1

	Distance from the track (cm)				
	0	70	120	260	400
Ground hardness (kg cm^{-2})					
In-use road	12.8^a (1.40)	2.2^b (0.65)	1.5^b (0.35)	1.1^b (0.28)	1.2^b (0.29)
Abandoned road	0.4^b (0.08)	0.7^b (0.12)	0.8^b (0.11)	0.9^b (0.20)	0.4^b (0.06)
Soil water content (%)					
In-use road	10.1^a (0.35)	$6.1^{b,c}$ (0.40)	5.5^c (0.19)	$5.6^{b,c}$ (0.18)	5.4^c (0.26)
Abandoned road	$6.1^{b,c}$ (0.30)	7.0^b (0.38)	$6.3^{b,c}$ (0.53)	5.3^c (0.16)	5.3^c (0.16)

Data were pooled over survey occasions (ground hardness in July 2008, September 2008, and August 2009; soil water content in July and September 2008). Values labeled with different superscript lowercase letters differ significantly among distances and road types (Tukey–Kramer test; $P < 0.05$). Values in parentheses represent ±1 standard error ($n = 11$ for ground hardness, $n = 8$ for soil water content)

Discussion

The effect of vehicle-track formation on the productivity of Mongolian steppe vegetation was spatially limited. Statistically significant decreases in aboveground biomass and vegetation cover at the in-use road were found only within the tracks and not in adjacent plots (Fig. 2; Table 2). In contrast to our results, other studies report that vegetation productivity and cover sometimes increase along the sides of a dirt road, which is one example of the "edge effect" (Johnson et al. 1975; Vasek et al. 1975; Hessing and Johnson 1982). Runoff water from the road surface is captured by roadside berms, where it enhances the growth of roadside vegetation (Johnson et al. 1975; Starr and Mefford 2002; Brooks and Lair 2005). The lack of an edge effect in our study may be attributed to the fact that the dirt roads we investigated were unimproved and had no berms (Fig. 1). In a previous study, edge effects were not found even beside improved dirt roads when berms were absent (Starr and Mefford 2002).

In general, vehicle passage compacts the soil, which decreases rain infiltration into the soil and thereby reduces soil moisture in the tracks (Webb et al. 1978; Wilshire et al. 1978; Dregne 1983; Webb 2002). However, we found increased soil water content under the track, even though soil hardness increased as a result of vehicle traffic (Table 3). This increase may have been caused by an enhancement of soil water retention potential and/or reduction in evapotranspiration in compacted soil. Compacting the soil compresses its macropores, thereby creating more micropores and increasing the soil's potential for water retention (Richard et al. 2001; Sillon et al. 2003; Ampofo 2006). In addition, the decrease in soil pore volume by compaction impedes vapor movement and consequently evaporation (Warkentin 1971; Sillon et al. 2003). The lower amount of vegetation in the tracks may have reduced the removal of soil water by root uptake and transpiration.

Aboveground biomass and vegetation cover in the track recovered to nearly the same level as in the vegetation outside of the track by 4–6 years after abandonment of the dirt road (Fig. 2; Table 2). This recovery was far quicker than in a previous study in the central Mongolian steppe (Li et al. 2006), in which vegetation had recovered to only 46 % of the cover value in native steppe 3–5 years after abandonment. This difference in recovery rates may be attributed to the degree of soil compaction created during the use of the dirt road, because the recovery rate of vegetation sometimes depends on the degree of soil compaction (Webb and Wilshire 1980; Payne et al. 1983). In fact, ground hardness of in-use tracks investigated by Li et al. (2006) was about 25 times greater than that in our study, although ground hardness of the native steppe in that study was similar to that in the plot farthest from the track in our study. The photo of the dirt road studied by Li et al. (2006) shows that there was no vegetation between the tracks, implying that the frequency of vehicle passage was higher and therefore the compaction effect may have been greater than in our study. Because root growth is inhibited by soil compaction, natural loosening of the compacted soil in a track is critical for vegetation recovery (Webb et al. 1983; Lovich and Bainbridge 1999; Batey 2009; Tracy et al. 2011). Natural soil loosening is a relatively slow process and depends on climatic processes, such as wetting–drying and freeze–thaw cycles, as well as on biological activities such as burrowing by rodents and penetration by plant roots (Webb et al. 1983, 1986; Knapp 1992; Webb 2002). Thus, the degree of compaction during the use of dirt roads strongly affects the recovery rate of vegetation in the tracks.

Tracks in dirt roads are a source of emission of wind-eroded dust because of their low vegetation cover (Gillette and Adams 1983; Goossens and Buck 2009a, b). The Mongolian steppe is a major source of dust emission in Asia (Zhang et al. 2008; Shinoda et al. 2011). Wind-blown dust is sometimes transported long distances and causes human disease in downwind countries such as Korea, Taiwan, and Japan (Kwon et al. 2002; Yang et al. 2005; Hashizume et al. 2010). In temperate grasslands, the threshold vegetation cover above which wind erosion is eliminated is typically 15–20 % (Lancaster and Baas 1998; Kimura et al. 2009; Shinoda et al. 2011). At the dirt road we investigated, vegetation cover in the tracks had recovered from nearly zero to >25 % by 4–6 years after abandonment (Fig. 2; Table 2), which suggests that the abandoned tracks in our study were no longer a significant source of dust emission. Because the recovery rate of vegetation sometimes depends on the degree of soil compaction, traffic volume on a dirt road may determine the period during which the road will be a source of wind-blown dust emission after its abandonment. However, it is important to note that the vegetation cover in the spring, at a time of year when strong winds are common in the Mongolian steppe, can be sparser than the cover during our observation period (cf. Shinoda et al. 2010, 2011).

The amount of *A. adamsii* and its fraction of the aboveground biomass increased at the abandoned road, especially around the tracks (Fig. 3; Table 2), which appears to have resulted from an increase in the number of shoots rather than in the biomass per shoot (Fig. 4). The increase in shoot number of *A. adamsii* can be attributed to recruitment through seed germination and shoot production with rhizome expansion. *A. adamsii* produces several small seeds, and their germination percentage reached 60 % at 17 °C when light was sufficient (Ishibashi, unpublished data). After germination, rhizomes of *A. adamsii* elongated approximately 30 cm in 5 months (Ishibashi, unpublished data). Thus, seeds of *A. adamsii* may have germinated in the abandoned tracks, where light was sufficient for germination, and then the species expanded out of the tracks. In addition, if *A. adamsii* has high root penetration ability in compacted soil, the species may have an advantage in colonization of abandoned tracks, and this may explain its abundance on the abandoned road. However, root penetration ability of grassland species in Mongolia has not been investigated, but interspecific variation in root penetration ability has been demonstrated in agricultural crops (Materechera et al. 1991). *A. adamsii*, on colonizing abandoned tracks with sparse vegetation, may have photosynthesized effectively and redistributed photosynthates among shoots through physiological integration (Pitelka and Ashmun 1985), thereby producing many shoots and invading the vegetation outside of the tracks. Clonal species sometimes invade the vegetation occupied by other species (Cook 1985), an activity suggested to be advantageous by preventing the establishment of other species by clonal occupation of large areas (Sebens and Thorne 1985). The increase in the abundance of *A. adamsii* may decrease pasture quality because it is unpalatable to most livestock (Jigjidsuren and Johnson 2003; Damiran 2005). The recovery of grassland productivity (quantity) was therefore not accompanied by a comparable recovery in pasture quality in our study area.

In summary, because the dirt roads in the Mongolian steppe we investigated sustained relatively low vehicle traffic, the disturbance of grassland productivity was relatively limited. Vegetation cover and aboveground biomass had almost recovered to the levels in undisturbed steppe by 4 years after road abandonment, and this degree of recovery would eliminate dust emission from the tracks during the growing season. However, a low-palatability clonal herb, *A. adamsii*, increased its abundance by producing many shoots in and around the abandoned tracks, thereby decreasing the quality of pasture. We conclude that vegetation recovery in the tracks of an abandoned dirt road can affect the surrounding vegetation through colonization by and expansion of clonal species such as *A. adamsii*. Thus, to evaluate natural vegetation recovery after dirt-road abandonment, changes in vegetation not only within but also around abandoned tracks should be investigated.

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