GRASSLAND SCIENCE

Japanese Society of Grassland Science

Japanese Society of Grassland Science ISSN1744-6961

ORIGINAL ARTICLE

Response of degraded vegetation to introduction of prescribed burning or mowing management in a Mongolian steppe

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Keywords
Artemisia adamsii; ecosystem management; raunkiaer life form; resprouting.

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Received 9 February 2015; accepted 12 September 2015.

doi: 10.1111/grs.12113

Abstract

The understanding of the effectiveness of prescribed burning and mowing as restoration tools of degraded grasslands is important for dryland rangeland management. We examined the effects of spring prescribed burning or seasonal mowing treatments on the degraded vegetation dominated by an unpalatable subshrub, *Artemisia adamsii*, in grazed Mongolian steppe. Spring burning was conducted in 2013, and three types of mowing treatments (spring, previous summer, and previous summer and autumn) were conducted with varying seasons and frequency, respectively. Soil samples were collected immediately after the spring treatments. Four months after the spring treatments, total plant biomass, the numbers of flowering shoots and florets per shoot of *A. adamsii* were compared among the treatments. Plant biomass was divided into *A. adamsii* and herbaceous plants (forbs and graminoids) with different Raunkiaer life forms (chamaephytes, hemicryptophytes and geophytes). Soil properties and total plant biomass were not different among the treatments. For *A. adamsii*, the biomass and number of flowering shoots were decreased by spring burning and growing-season mowing, owing to the disappearance of woody-shoots of *A. adamsii*. On the other hand, spring mowing had less negative impact on the biomass of *A. adamsii* due to an increase of the newly-formed shoots. The biomass of perennial herbaceous-plants was not affected by spring burning, regardless of the life form, whereas that of the geophytic sedge *Carex duriuscula* increased in the summer-and-autumn mowing. Thus, spring burning and growing-season mowing have the potential to control undesirable subshrubs due to loss of the woody shoots, while spring mowing may not be recommended as a useful management tool in the Mongolian steppe. Our results emphasize that the introduction of these management tools for degraded-grassland restoration in dryland rangelands needs more long-term evaluation considering the relation with external factors such as climate variation and grazing impact.

Introduction

In arid and semiarid Mongolian rangelands, land degradation has progressed under overgrazing by livestock, with a shift from vegetation dominated by palatable grasses to that dominated by unpalatable forbs and weeds (Fernandez-Gimenez and Allen-Diaz 2001; Sasaki *et al.* 2008, 2013b). The predominance of an unpalatable subshrub *Artemisia adamsii* Besser in overgrazed grasslands is a serious concern for rangeland management in the Mongolian steppe (Fernandez-Gimenez and Allen-Diaz 2001; Okayasu *et al.* 2012; Tsubo *et al.* 2012). Restoration of degraded grasslands to desirable grasslands often needs introduction of novel management tools (Antonsen and Olsson 2005; Seastedt *et al.* 2008). Although grassland management, such as burning or mowing except for grazing, has not historically been used in Mongolian rangelands, examining the response of degraded Mongolian vegetation to grassland management tools is warranted based on its success in other ecosystems.

Prescribed burning is regarded as an effective restoration tool for degraded vegetation in grasslands (Peet *et al.* 1999; Antonsen and Olsson 2005). Prescribed burning helps to control undesirable invasive annuals or unpalatable perennial species due to removal of the seedbank and aboveground biomass (McDaniel *et al.* 1997; Moyes *et al.* 2005; DiTomaso *et al.* 2006). Post-fire grass production often increases with the improved light conditions, increased soil temperature and soil mineral elements, and decreased competition (Davies *et al.* 2007; Rau *et al.* 2008; Augustine and Milchunas 2009; Allen *et al.* 2011). However, the effect of prescribed burning on the survival of perennial species is often small, and its effect on regrowth and reproduction can be either positive or negative (Anderson and Menges 1997; Drewa *et al.* 2006). Although the introduction of prescribed burning to degraded grassland restoration has been attempted in some ecosystems (Liira *et al.* 2009; Valkó *et al.* 2014), there is uncertainty as to the effectiveness of prescribed burning as a rangeland management tool (Kulpa *et al.* 2012; Toledo *et al.* 2012). On the other hand, mowing is a frequently-used grassland management tool with various seasons and frequency (Bobbink and Willems 1993). Mowing can contribute to maintain plant production, species diversity and high foliage quality in grasslands (Kahmen *et al.* 2002; Bernhardt-Römermann *et al.* 2011).

Raunkiaer life forms (Raunkiaer 1934), which are defined based on the location of perennating buds, have been shown to be related to plant resprouting and reproduction in response to burning (Overbeck and Pfadenhauer 2007; Pyke *et al.* 2010), in combination with the season of burning (Engle and Bidwell 2001; Lesica and Martin 2003). Dormant-season burning (i.e. early-spring burning) removes only weathered aboveground biomass, whereas growing-season burning (i.e. summer and autumn burning) damages both previous-year and current-year aboveground parts. Therefore, spring burning may inhibit the regrowth of chamaephytes, which have winter buds at the soil surface, but may not affect the regrowth of hemicryptophytes and geophytes, which form winter buds at the soil surface or below ground (Brockway *et al.* 2002; Pyke *et al.* 2010; Burnett *et al.* 2012). Prescribed burning and mowing can have similar impacts on plant responses related to the life forms (Peet *et al.* 1999; MacDougall and Turkington 2007). Thus, the use of mowing as a grassland restoration tool has often been considered in substitution for the (re)introduction of prescribed burning having relatively high risk (Castellnou *et al.* 2010; Mause *et al.* 2010; Halpern *et al.* 2012).

The aim of this study was to examine the effectiveness of introduction of grassland management, i.e. prescribed burning and seasonal mowing, to the control of *A. adamsii*-dominated vegetation in degraded Mongolian rangelands. Spring burning, which is frequently used and expected to have less negative impact on plant production (Brockway *et al.* 2002; Fuhlendorf *et al.* 2009), and seasonal mowing were attempted. In particular, we measured the short-term responses in the regrowth and reproduction of *A. adamsii* and herbaceous plants to address: (i) whether spring prescribed burning and seasonal mowing reduce the regrowth and reproduction of the subshrub *A. adamsii*, and (ii) whether the response of herbaceous plants to burning or mowing is related to their Raunkiaer life forms.

Materials and methods

Study site

The study was conducted at the Hustai National Park (HNP; 47°50′N, 106°00′E), 100 km west of Ulaanbaatar, Mongolia. The climate is arid and cold; the average annual precipitation is 232 mm, and the average annual temperature is 0.2°C. Average monthly temperature ranges from −20.6°C in January to 19.0°C in July. The annual precipitation before and during the experiments was general, i.e. 267 mm in 2012 and 228 mm in 2013. The park covers approximately 600 km^2 and consists of grassland, shrubland and forest steppe (Wallis de Vries *et al.* 1996; Bayarsaikhan *et al.* 2009). The main livestock are sheep, goats, horses and cattle, and wild horses also live in the area. The grassland area has been degraded by grazing, and the number of livestock in the protected area of HNP has been restricted for conservation purposes since 1992 (Bayarsaikhan *et al.* 2009). The principal palatable perennial graminoids are *Carex duriuscula*, *Agropyron cristatum* P. Beauv., *Elymus chinensis* (Trin.) Keng and *Stipa krylovii* Roshev. (Yoshihara *et al.* 2009, 2010; Sasaki *et al.* 2013a). Annual plants are less in this area. The unpalatable perennial forb *Artemisia adamsii* has spread widely in the degraded grasslands (Wallis de Vries *et al.* 1996; Okayasu *et al.* 2012). *Artemisia adamsii* forms woody stems, and current-year shoots sprout via clonal expansion (Jigjidsuren and Johnson 2003; Kinugasa *et al.* 2012). The plant height is 15–40 cm, and it flowers from June to October.

Experiments

In June 2012, we selected four sites (28 × 35 m) in *A. adamsii*–dominated communities at 1-km intervals along the same gentle eastern-facing slope. We set 24 plots (3 × 3 m) in a 4 × 6 matrix at 2-m intervals. In the plots, we randomly conducted five treatments (spring prescribed burning, spring mowing, summer mowing, summer-and-autumn mowing and an unmanaged control) with four replications. The four residual plots were not used. Spring prescribed burning was conducted using gas grass firing burner (Kusayaki GT-100, Shinfuji, Japan) in early May 2013 (Figure 1). The immediate post-fire temperature at the soil surface was 80–90°C. The mowing treatments were conducted in early May 2013 for spring mowing, in August 2012 for summer mowing and in August and October 2012 for summer-and-autumn mowing. The aboveground parts of all plants were removed by mowing. The four sites were fenced soon after the burning treatment to prevent disturbance from livestock and wildlife.

Soil analysis

Soil sampling was conducted immediately after the spring burning treatment. We collected soil samples (10-cm depth) from each plot, and mixed the four soil samples as one bulk sample for each treatment at each site. The soil samples were air-dried and then analyzed. Soil pH was measured with a glass electrode, and electric conductivity (EC) was measured with an EC meter. Soil carbon contents were analyzed by using dry combustion. Exchangeable soil Ca and available K_2O were measured using atomic absorption spectrophotometry. Available soil phosphorus (P_2O_5) was measured using the Truog–Bray method.

Figure 1 Prescribed burning experiment conducted in *Artemisia adamsii*-dominated grasslands at the Hustai National Park, Mongolia.

Plant survey

In August 2013, we conducted a vegetation survey in a 1 × 1 m quadrat within each plot and measured the percent cover of all plant species. We took a sample of aboveground plant biomass from a 50 × 50 cm subquadrat within each quadrat at the same time. The samples were divided into six classes based on Raunkiaer life forms and plant functional types (Grubov 1982; Jigjidsuren and Johnson 2003; Wesche *et al.* 2006): chamaephytes, (i) *A. adamsii* and (ii) chamaephytic forbs excluding *A. adamsii* (e.g. *Artemisia frigida* Willd.); hemicryptophytes, (iii) hemicryptophytic forbs (e.g. *Convolvulus ammannii* Desr. and *Cymbaria dahurica* L.) and (iv) hemicryptophytic grasses (e.g. *S. krylovii* and *Cleistogenes squarrosa* (Trin.) Keng); geophytes, (v) geophytic sedge (i.e. *C. duriuscula*); and (vi) others including annual plants. The *A. adamsii* sample was further divided into three parts: current-year shoots, woody shoots (i.e. previous-year shoots) and litter. The samples were oven-dried to constant weight at 75°C for 48 h.

To compare the reproductive ability of *A. adamsii* among the treatments, the numbers of flowering shoots and florets per shoot were counted for previous- and current-year shoots, respectively.

Statistical analysis

Soil properties, plant biomass and *A. adamsii* reproduction were compared among the five treatments using generalized linear mixed models, with site ID as a random intercept. We used the Gamma error distribution for soil properties, the Gaussian error distribution for plant biomass (because it included zero data), and the Poisson error distribution for the numbers of flowering shoots and florets of *A. adamsii*. Tukey's test for multiple comparisons was applied using the glht (general linear hypothesis testing) function in the multcomp package of R ver. 3.0.3 (R Core Team 2014).

Results

Soil pH, organic carbon, Ca, P_2O_5 and K_2O did not show significant differences among the treatments, whereas EC tended to be higher in the summer mowing treatment and lower in the summer-and-autumn mowing treatment (Table 1).

We recorded 40 plant species in total (5.9 ± 3.4 per quadrat). In the control, the cover of *A. adamsii* predominated (40 ± 16%), followed by the geophytic sedge

Table 1 Soil properties (mean ± SD) in the five experimental treatments

			Mowing		
Property	Control	Spring burning	Spring	Summer	Summer and autumn
pH	6.0 ± 0.2[a]	6.2 ± 0.7[a]	6.2 ± 0.6[a]	6.2 ± 0.6[a]	6.1 ± 0.6[a]
EC (dS m^{-1})	0.04 ± 0.01[ab]	0.07 ± 0.06[ab]	0.06 ± 0.05[ab]	0.08 ± 0.06[a]	0.04 ± 0.01[b]
Organic carbon (%)	4.1 ± 0.2[a]	3.8 ± 0.3[a]	4.2 ± 0.5[a]	4.2 ± 0.8[a]	4.2 ± 0.4[a]
Ca (mg 100 g^{-1})	22.1 ± 4.0[a]	21.0 ± 2.9[a]	21.1 ± 1.7[a]	21.5 ± 2.5[a]	21.2 ± 2.6[a]
P_2O_5 (mg 100 g^{-1})	3.9 ± 1.3[a]	3.8 ± 1.6[a]	3.8 ± 0.8[a]	3.7 ± 1.2[a]	3.0 ± 1.5[a]
K_2O (mg 100 g^{-1})	61.0 ± 24.7[a]	56.0 ± 20.8[a]	60.0 ± 26.9[a]	59.0 ± 25.0[a]	56.5 ± 22.6[a]

Values of a parameter followed by different letters differ significantly between treatments at $P < 0.05$.

(25 ± 19%), hemicryptophytic grasses (16 ± 11%), chamaephytic forbs (6 ± 15%), hemicryptophytic forbs (4 ± 5%) and others (less than 1%). Total plant biomass was not different among the five treatments (Figure 2a). For *A. adamsii*, the biomass was decreased by the spring burning treatment and the summer and summer-and-autumn mowing treatments (Figure 2b). Spring burning and mowing completely removed the previous-year shoots of *A. adamsii* and the litter (Figure 2c,d). On the other hand, the biomass of current-year shoots was not decreased by burning and growing-season mowing and was increased by spring mowing (Figure 2e). The biomass of chamaephytic forbs and hemicryptophytic forbs and grasses did not differ among the five treatments (Figure 2f–h). In contrast, the biomass of geophytic sedge tended to increase in mowing treatments, and was significantly greater in the summer-and-autumn mowing treatment (Figure 2i).

For *A. adamsii*, the number of flowering shoots was decreased by spring burning and the three mowing treatments (Figure 3a). However, the number of current-year flowering shoots tended to increase in the spring burning and mowing treatments with the disappearance of previous-year flowering shoots (Figure 3b,c). This was also the case for the number of florets per shoot (Figure 3d).

Discussion

Spring prescribed burning and growing-season mowing decreased the biomass and reproduction of unpalatable A. *adamsii* in a degraded Mongolian rangeland. Spring prescribed burning completely removed the woody shoots of *A. adamsii*, but it did not negatively affect the biomass and flowering of the current-year shoots. Dormant-season burning would have little influence on post-fire plant cover and reproduction of perennial herbaceous plants (Brockway *et al.* 2002; Augustine and Milchunas 2009), because the burning does not affect the belowground parts in low-productivity ecosystems (Burnett *et al.* 2012). Indeed, the impact of prescribed burning on soil properties and plant production was weak in the Mongolian steppe, probably owing to the lack of plant fuel, including litter (Allen *et al.* 2011). On the other hand, a previous study showed that spring burning reduced the clone size of a clonal grass (Drewa *et al.* 2006). For *A. adamsii*, although the loss of woody shoots may increase the plant's investment in the current-year shoots, spring prescribed burning would totally reduce the biomass and reproduction of subshrub *A. adamsii* as a result of the loss of the woody shoots. We also found that spring prescribed burning did not affect the regrowth of perennial herbaceous species, regardless of the Raunkiaer life form classification. Prescribed burning has been used as a management tool for woody plants and subshrubs (McDaniel *et al.* 1997; Augustine and Milchunas 2009). Woody plants should be susceptible to damage by spring burning, unlike perennial herbaceous species, which have little aboveground biomass in spring to be directly damaged.

Spring mowing showed no negative impact on the biomass and flowering of *A. adamsii* due to increase in the biomass and reproduction of current-year shoots. On the other hand, growing-season mowing decreased the total biomass and reproduction of *A. adamsii*. The results of our mowing treatments also suggest that frequent growing-season mowing may lead to a greater reduction of the cover of *A. adamsii*, rather than spring burning (Antonsen and Olsson 2005). These suggest that not spring mowing but growing-season mowing would be recommended as a useful management tool to control the dominance of *A. adamsii*. We also found that the cover of the geophytic sedge (*C. duriuscula*) increased in response to frequent growing-season mowing, probably because of a decrease in the cover of *A. adamsii* (Augustine and Milchunas 2009). Geophytic species increases the cover under aboveground-removal management using burning, grazing and mowing (McIntyre *et al.* 1995; Kahmen *et al.* 2002). The ability of sedge species to tiller and spread their shoots would also enhance the rapid response to the decrease of *A. adamsii* cover after frequent growing-season mowing (Pywell *et al.* 2003).

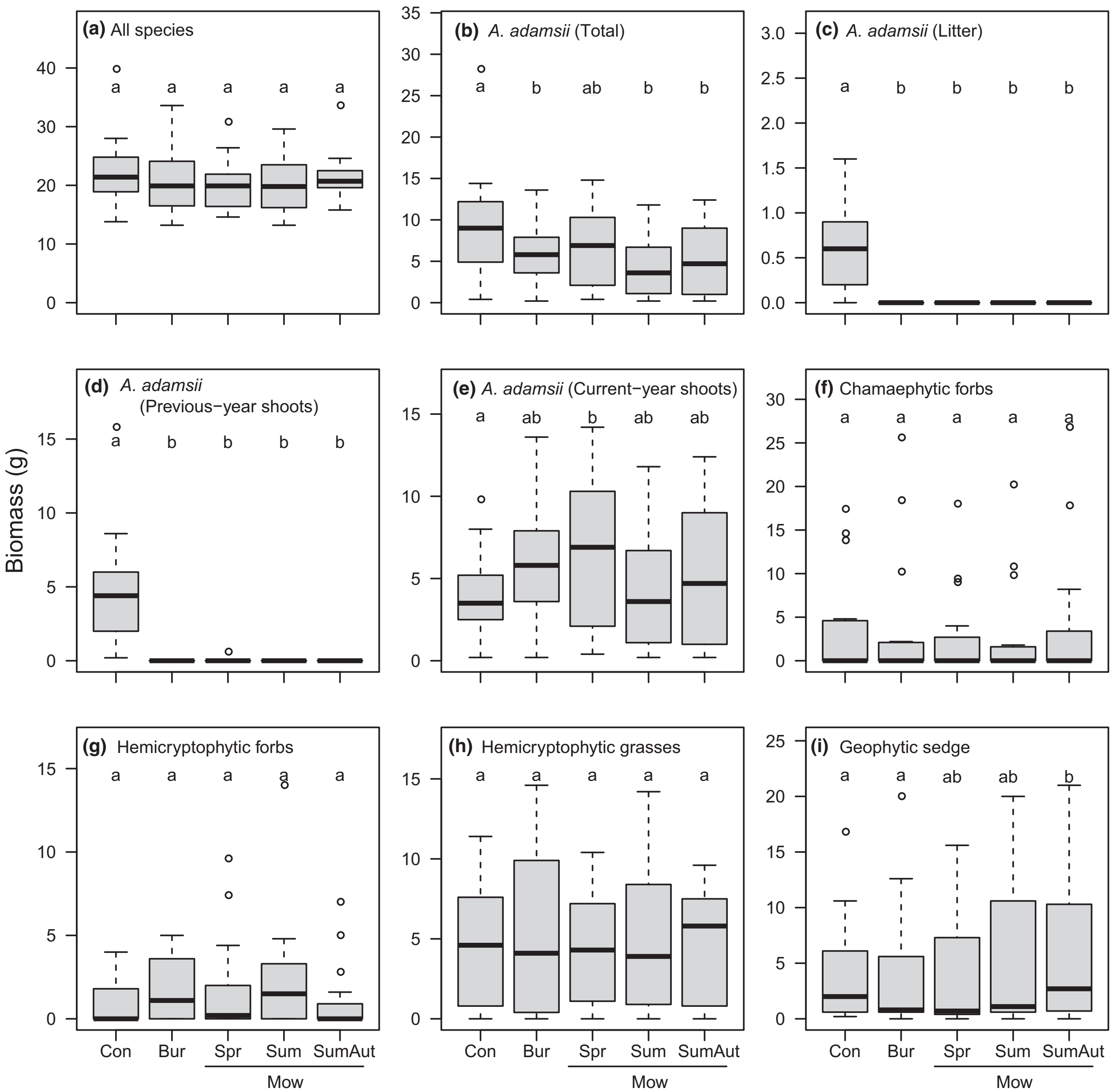

Figure 2 Plant biomass of (a) all species, (b–e) different parts of *Artemisia adamsii* and (f–i) herbaceous species with different Raunkiaer life forms in five experimental treatments (Con, control; Bur, burning; Mow, mowing; Spr, spring; Sum, summer; SumAut, summer and autumn). Box-and-whisker plots indicate 75th, 50th and 25th percentiles; the top whisker ranges from the 75th to 90th percentile, and the bottom from the 25th to 10th percentile. Circles show outliers. Different letters show a significant difference at $P < 0.05$.

Conclusion

Few studies have examined the use of prescribed burning and mowing for vegetation control and management in degraded rangelands of arid and semiarid ecosystems. Our results suggest that spring prescribed burning and growing-season mowing have the potential to control undesirable subshrubs in degraded vegetation dominated by perennial grasses. These results lead us to propose the effectiveness of use of grassland management tools focused on the difference of life forms between undesirable and desirable plants. In this study, one-time spring burning and the short-term responses of Mongolian vegetation was attempted because the introduction of prescribed burning to grasslands without the history of prescribed burning needs careful examination. However,

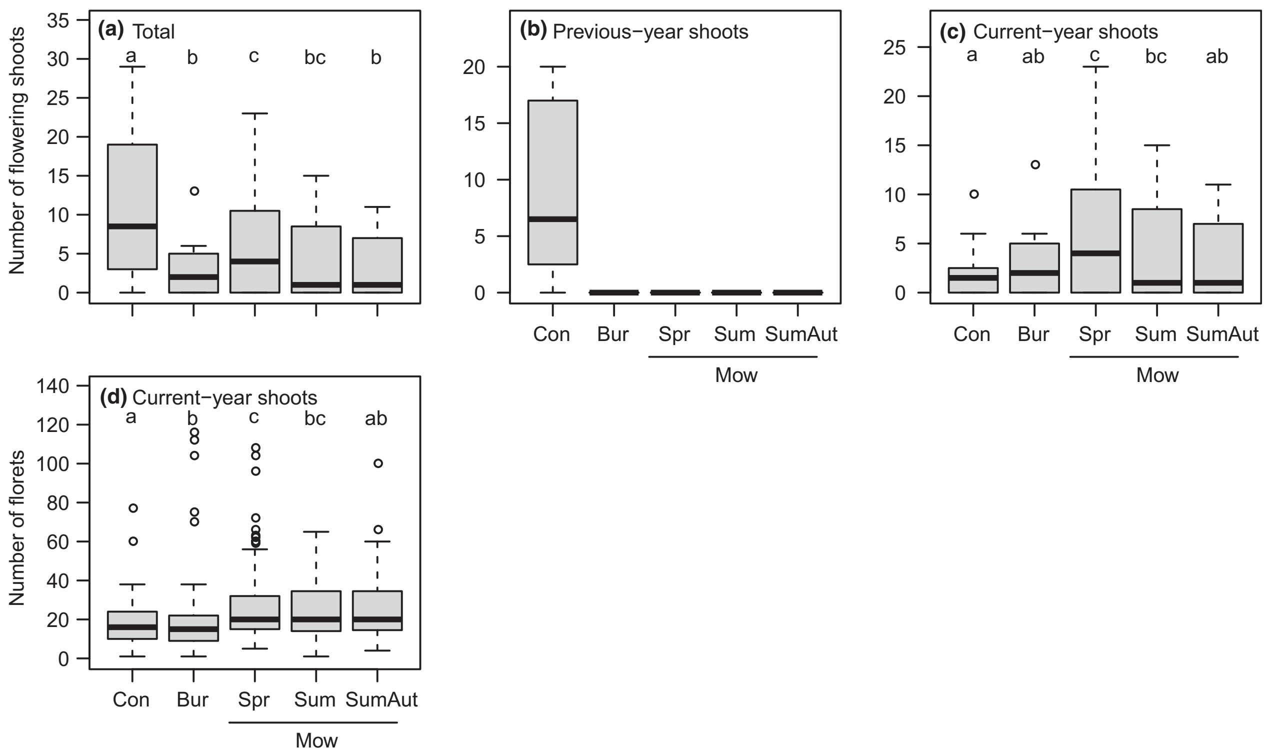

Figure 3 The numbers of (a–c) flowering shoots with different parts and (d) florets per shoot for *Artemisia adamsii* in five experimental treatments. Values labeled with different letters differ significantly at $P < 0.05$.

vegetation responses to sustained prescribed burning or mowing treatments should be changeable in relation to external factors such as post-fire precipitation and grazing pressure (Engle and Bidwell 2001; Augustine and Milchunas 2009; Koyama *et al.* 2015). Additionally, the introduction of prescribed burning to degraded rangelands has potential risks, and that of growing-season mowing has relatively high cost (MacDougall and Turkington 2007; Valkó *et al.* 2014). A long-term evaluation of vegetation responses to the grassland management is needed to better quantify the effectiveness of introduction of management tools for restoration of degraded Mongolian rangelands.

Acknowledgments

This research was funded by the Global Environmental Fund of the Ministry of the Environment of Japan (D-1105) and by the Mitsui & Co. Environment Fund (R10-B196).

References

Allen EB, Steers RJ, Dickens SJ (2011) Impacts of fire and invasive species on desert soil ecology. *Range Ecol Manag* 64: 450–462.

Anderson R, Menges E (1997) Effects of fire on sandhill herbs: nutrients, mycorrhizae, and biomass allocation. *Am J Bot* 84: 938–948.

Antonsen H, Olsson PA (2005) Relative importance of burning, mowing and species translocation in the restoration of a former boreal hayfield: responses of plant diversity and the microbial community. *J Appl Ecol* 42: 337–347.

Augustine DJ, Milchunas DG (2009) Vegetation responses to prescribed burning of grazed shortgrass steppe. *Range Ecol Manag* 62: 89–97.

Bayarsaikhan U, Boldgiv B, Kim KR, Park KA, Lee D (2009) Change detection and classification of land cover at Hustai National Park in Mongolia. *Int J Appl Earth Obs Geoinf* 11: 273–280.

Bernhardt-Römermann M, Römermann C, Sperlich S, Schmidt W (2011) Explaining grassland biomass: the contribution of climate, species and functional diversity depends on fertilization and mowing frequency. *J Appl Ecol* 48: 1088–1097.

Bobbink R, Willems JH (1993) Restoration management of abandoned chalk grassland in the Netherlands. *Biodivers Conserv* 2: 616–626.

Brockway DG, Gatewood RG, Paris RB (2002) Restoring fire as an ecological process in shortgrass prairie ecosystems: initial effects of prescribed burning during the dormant and growing seasons. *J Environ Manage* 65: 135–152.

Burnett SA, Hattey JA, Johnson JE, Swann AL, Moore DI, Collins SL (2012) Effects of fire on belowground biomass in Chihuahuan Desert grassland. *Ecosphere* 3: art107.

Castellnou M, Kraus D, Miralles M (2010) Prescribed burning and suppression fire techniques: from fuel to landscape management. In: *Best Practices of Fire Use: Prescribed Burning and Suppression Fire Programmes in Selected Case-Study Regions in Europe* (Eds Montiel C, Kraus D), European Forest Institute Research Report 24, WS Bookwell Oy, Porvoo, 3–16.

Davies KW, Bates JD, Miller RF (2007) Short-term effects of burning Wyoming big sagebrush steppe in southeast Oregon. *Range Ecol Manag* 60: 515–522.

DiTomaso JM, Brooks ML, Allen EB, Minnich R, Rice PM, Kyser GB (2006) Control of invasive weeds with prescribed burning. *Weed Technol* 20: 535–548.

Drewa P, Peters DC, Havstad K (2006) Population and clonal level responses of a perennial grass following fire in the northern Chihuahuan Desert. *Oecologia* 150: 29–39.

Engle DM, Bidwell TG (2001) Viewpoint: the response of central North American prairies to seasonal fire. *J Range Manag* 54: 2–10.

Fernandez-Gimenez M, Allen-Diaz B (2001) Vegetation change along gradients from water sources in three grazed Mongolian ecosystems. *Plant Ecol* 157: 101–118.

Fuhlendorf SD, Engle DM, Kerby J, Hamilton R (2009) Pyric herbivory: rewilding landscapes through the recoupling of fire and grazing. *Conserv Biol* 23: 588–598.

Grubov VI (1982) *Key to the Vascular Plants of Mongolia*. Science Publishers Inc, Enfield, 1–411.

Halpern CB, Haugo RD, Antos JA, Kaas SS, Kilanowski AL (2012) Grassland restoration with and without fire: evidence from a tree-removal experiment. *Ecol Appl* 22: 425–441.

Jigjidsuren S, Johnson DA (2003) *Forage Plants in Mongolia*. Admon Publishing Co, Ulaanbaatar, 1–563.

Kahmen S, Poschlod P, Schreiber KF (2002) Conservation management of calcareous grasslands. Changes in plant species composition and response of functional traits during 25 years. *Biol Conserv* 104: 319–328.

Kinugasa T, Tsunekawa A, Shinoda M (2012) Increasing nitrogen deposition enhances post-drought recovery of grassland productivity in the Mongolian steppe. *Oecologia* 170: 857–865.

Koyama A, Yoshihara Y, Jamsran U, Ohkuro T (2015) Role of tussock morphology in providing protection from grazing for neighbouring palatable plants in a semi-arid Mongolian rangeland. *Plant Ecol Divers* 8: 163–171.

Kulpa SM, Leger EA, Espeland EK, Goergen EM (2012) Post-fire seeding and plant community recovery in the Great Basin. *Range Ecol Manag* 65: 171–181.

Lesica P, Martin B (2003) Effects of prescribed fire and season of burn on recruitment of the invasive exotic plant, *Potentilla recta*, in a semiarid grassland. *Restor Ecol* 11: 516–523.

Liira J, Issak M, Jõgar Ü, Mändoja M, Zobel M (2009) Restoration management of a floodplain meadow and its cost-effectiveness: the results of a 6-year experiment. *Ann Bot Fenn* 46: 397–408.

MacDougall AS, Turkington R (2007) Does the type of disturbance matter when restoring disturbance-dependent grasslands? *Restor Ecol* 15: 263–272.

Mause R, Kraus D, Held A (2010) The use of prescribed fire for maintaining open *Calluna* heathlands in north Rhine-Westphalia, Germany. In: *Best Practices of Fire Use: Prescribed Burning and Suppression Fire Programmes in Selected Case-Study Regions in Europe* (Eds Montiel C, Kraus D), European Forest Institute Research Report 24, WS Bookwell Oy, Porvoo, 77–88.

McDaniel KC, Hart CR, Carroll DB (1997) Broom snakeweed control with fire on New Mexico blue grama rangeland. *J Range Manag* 50: 652–659.

McIntyre S, Lavorel S, Tremont RM (1995) Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *J Ecol* 83: 31–44.

Moyes AB, Witter MS, Gamon JA (2005) Restoration of native perennials in a California annual grassland after prescribed spring burning and solarization. *Restor Ecol* 13: 659–666.

Okayasu T, Okuro T, Jamsran U, Takeuchi K (2012) Degraded rangeland dominated by unpalatable forbs exhibits large-scale spatial heterogeneity. *Plant Ecol* 213: 625–635.

Overbeck GE, Pfadenhauer J (2007) Adaptive strategies in burned subtropical grassland in southern Brazil. *Flora* 202: 27–49.

Peet NB, Watkinson AR, Bell DJ, Sharma UR (1999) The conservation management of *Imperata cylindrica* grassland in Nepal with fire and cutting: an experimental approach. *J Appl Ecol* 36: 374–387.

Pyke DA, Brooks ML, D'Antonio C (2010) Fire as a restoration tool: a decision framework for predicting the control or enhancement of plants using fire. *Restor Ecol* 18: 274–284.

Pywell RF, Bullock JM, Roy DB, Warman LIZ, Walker KJ, Rothery P (2003) Plant traits as predictors of performance in ecological restoration. *J Appl Ecol* 40: 65–77.

R Core Team (2014) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Rau BM, Chambers JC, Blank RR, Johnson DW (2008) Prescribed fire, soil, and plants: burn effects and interactions in the central Great Basin. *Range Ecol Manag* 61: 169–181.

Raunkiaer C (1934) *The Life Forms of Plants and Statistical Plant Geography*. Claredon, Oxford. 1–632.

Sasaki T, Okayasu T, Jamsran U, Takeuchi K (2008) Threshold changes in vegetation along a grazing gradient in Mongolian rangelands. *J Ecol* 96: 145–154.

Sasaki T, Kakinuma K, Yoshihara Y (2013a) Marmot disturbance drives trait variations among five dominant grasses in a Mongolian grassland. *Range Ecol Manag* 66: 487–491.

Sasaki T, Ohkuro T, Kakinuma K, Okayasu T, Jamsran U, Takeuchi K (2013b) Vegetation in a post-ecological threshold state may not recover after short-term livestock exclusion in Mongolian rangelands. *Arid Land Res Manag* 27: 101–110.

Seastedt TR, Hobbs RJ, Suding KN (2008) Management of novel ecosystems: are novel approaches required? *Front Ecol Environ* 6: 547–553.

Toledo D, Kreuter UP, Sorice MG, Taylor CA (2012) To burn or not to burn: ecological restoration, liability concerns, and the role of prescribed burning associations. *Rangelands* 34: 18–23.

Tsubo M, Nishihara E, Nakamatsu K, Cheng Y, Shinoda M (2012) Plant volatiles inhibit restoration of plant species communities in dry grassland. *Basic Appl Ecol* 13: 76–84.

Valkó O, Török P, Deák B, Tóthmérész B (2014) Review: prospects and limitations of prescribed burning as a management tool in European grasslands. *Basic Appl Ecol* 15: 26–33.

Wallis de Vries MF, Manibazar N, Dügerlham S (1996) The vegetation of the forest-steppe region of Hustain Nuruu, Mongolia. *Vegetatio* 122: 111–127.

Wesche K, Pietsch M, Ronnenberg K, Undrakh R, Hensen I (2006) Germination of fresh and frost-treated seeds from dry central Asian steppes. *Seed Sci Res* 16: 123–136.

Yoshihara Y, Ohkuro T, Bayarbaatar B, Takeuchi K (2009) Effects of disturbance by Siberian marmots (*Marmota sibirica*) on spatial heterogeneity of vegetation at multiple spatial scales. *Grassl Sci* 55: 89–95.

Yoshihara Y, Okuro T, Buuveibaatar B, Undarmaa J, Takeuchi K (2010) Clustered animal burrows yield higher spatial heterogeneity. *Plant Ecol* 206: 211–224.