Chapter 5
Semi-Natural Grasslands Maintained by Controlled Burning in Japan: Air and Soil Temperature and Plant Diversity

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Abstract There are semi-natural grasslands that are maintained by mowing and livestock grazing in Japan, and some of them are maintained by burning. Mowing and grazing are carried out mainly in the summer when the plants are active, but burning is carried out from winter to spring, which is the dormant period of the plants. The temperature at the time of burning in spring is high above ground, but hardly rises underground, so the damage on plants is considered to be limited. The soil temperature after burning is high enough for seeds areto germinate even in spring when the air tem able perature is low. Many seedlings occur in the burned area because the soil temperature after burning rises. As a result, the biodiversity of semi-natural grasslands increases.

Keywords Grassland burning · Prescribed fire · Semi-natural grassland · Soil temperature · Vegetation structure

5.1 Introduction

The Japanese archipelago is located at latitudes 45° 31′ to 24°3′ N and longitude 122° 56′ to 145 °49′ E. The southern part of the Ryukyu Islands is included in the subtropical zone, and the northern part of Hokkaido is included in the subarctic zone. Most of the rest of the Japanese archipelago belongs to the temperate zone, but the southwestern side is generally classified as a warm temperate zone and the north-eastern side is generally classified as a cool temperate zone. The warm temperate zone is mainly occupied by evergreen broad-leaved trees, and the cool temperate zone is occupied by deciduous broad-leaved trees, both of which develop forest communities.

In most parts of Japan, the annual rainfall is in the range of 1000 mm to 3000 mm, which is sufficient for the formation of forest communities. Therefore, natural

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F. Li et al. (eds.), *River Basin Environment: Evaluation, Management and Conservation*, https://doi.org/10.1007/978-981-19-4070-5_5

grasslands are not distributed unless there are some special environments such as alpine zones with low temperature, dryness, and short growing period, coastal grassland with sandy and high salinity, and marshes with excessive water conditions. In Japan, grasslands that are widely and commonly found in areas from flatlands to mountains are semi-natural grasslands, which are premised on human management in order to establish them. Unlike artificial grasslands, semi-natural grasslands are herbaceous communities that are naturally established after human disturbance. The main management methods include mowing, burning, grazing, and combinations of these. If these are not done, the grasslands will grow to bushes in a few years and will transition to a forest community within a few decades. Among these semi-natural grasslands in Japan, the characteristics of burning and subsequent changes in vegetation will be described for grasslands that are managed by burning.

Regarding the effects on plants, reaping and grazing are likely to have similar effects in cutting the plants during the growing season of the plants. On the other hand, grassland burning is likely to be different from the former two in that it has the effect of burning during the dormant period of the plant. I will be explained the characteristics of grassland burning from that point of view.

5.2 Semi-Natural Grassland Maintained by Burning in Japan

Fertilizers made from grass resources such as barnyard manure, compost, and green manure used in agriculture in the past have now been replaced by industrially synthesized chemical fertilizers. In addition, cows and horses that need feed raised by most farmers for cargo handling and agricultural work have been replaced by tractors and other agricultural machinery powered by fuel. Many thatched roof houses (Photo 5.1) which is hard to maintain has changed to a farmhouse with a tin roof and a tiled roof, which is easy maintain. As a result, grasslands for obtaining grass resources are no longer needed around rural areas, and more than 90% of the area of semi-natural grasslands has disappeared compared to 100 years ago (Ogura 2012). Figure 5.1 shows that the grasslands are currently being burned to maintain the grasslands in Japan, and the locations of the grasslands covered in this paper are described place name.

The semi-natural grasslands maintained by grassland burning in Japan extend nationwide from Hokkaido to Kyushu, but are relatively few in Hokkaido and the Chubu region. In Mt. Aso, Akiyoshidai, Mt. Kanpu, Koshimizu Gensei-Kaen, etc., the excellent grassland view was evaluated and it was designated as a National park or a Quasi-national park. These grassland views should be maintained, but the grassland area has decreased as the lifestyles surrounding agriculture have changed. In Mt. Kanpu (Akita Prefecture), the grassland area within the range of the Quasi-national park decreased from 319 ha to 138 ha in the 40 years from 1975 to 2014 (Masui et al. 2017). With the decrease in grassland area, there are concerns about the

Photo 5.1 Thatched-roof houses that were once often seen in rural areas. The Gokayama village including these houses in this photo is designated as a World Heritage Site

extinction of grassland-based plants. For example, *Platycodon grandiflorum*, *Eupatorium japonicum* and *Patrinia scabrioides*, which have been known as the Seven Herbs of Autumn (Aki no Nanakusa), are currently designated as endangered species in the national and prefectural governments due to their lack of habitat.

In the grassland ecosystem maintained by burning, local peoples are diversified in their awareness of grassland burning. Some peoples think that burning for the purpose of improving the grass quality of the rangeland for grazing, while others are not particularly conscious of the purpose and have continued to burn for a long time. In addition, at Watarase Yusuichi (retarding basin), burning is set to grow high-quality Phragmites australis as a raw material for reed screen (Yoshizu), and there are also places where burning is set to maintain the grassland landscape and conserve endangered species.

5.3 Temperature During Grassland Burning

It is expected that if the grasslands are burned, high temperatures will be generated, which will have a considerable impact on the ecosystem. The effects of grassland burning on the ecosystem have been known for a long time, with direct effects such as high temperatures and burned to plant litter, and indirect effects such as the fall of charcoal and ash and changes in the soil conditions (Daubenmire 1968). Even if the

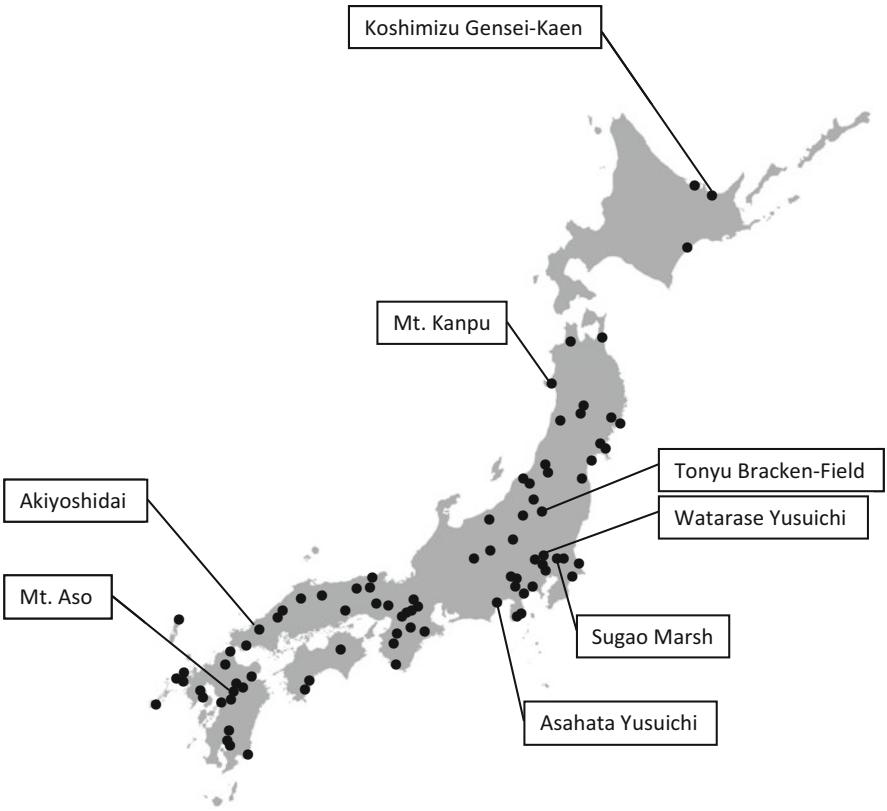

Fig. 5.1 Distribution of semi-natural grasslands managed by burning in Japan. The burned grasslands are indicated by dots, and the grasslands with the names are mentioned in the text

semi-natural grasslands in Japan are burned, the same effects as those of natural grasslands such as prairies should be brought to the ecosystem, so the temperature environment was measured by burning of semi-natural grassland in various places in Japan.

For temperature measurement during grassland burning, six sheath-type K thermocouples were connected to a data logger (Thermic, medel 2300A or 2400A manufactured by Eto Electric Co., Ltd.), as one set. The temperatures in the air at heights of +100 cm and +30 cm, on the ground surface (±0 cm), and in the soil at depths of −2 cm, −5 cm, and −10 cm were recorded at 1-s intervals. The recording device (Thermic) was sealed in a vinyl bag and buried underground, and the electrical wire of the thermocouple was heat-resistant with glass wool, ceramic fiber, heat-resistant aluminum tape, etc. to prevent disconnection due to heating (Photo 5.2).

Figure 5.2 shows the temperature changes during burning in several different types of grasslands. When a community of tall plants such as *Phragmites australis* and *Miscanthus sacchariflorus* with a plant height of 3–4 m is burned, the

Photo 5.2 A system for measuring the burning temperature of grasslands

temperature rises to 700–800 ° C above the ground. On the other hand, when a community with a plant height of about 1–2 m, such as Miscanthus sinensis, Leymus mollis, and Miscanthus intermedius, is burned, the temperature rises only to about 300–500 °C, and in the case of plant height of about 10 cm such as Zoysia japonica, the temperature of the above-ground part rises only up to about 100 ° C. It takes a very short time for temperature sufficient to kill the plant and high temperature lasts for only a few minutes during burning. This is not affected by the type of semi-natural grassland. Furthermore, it can be seen that the lethal temperature is reached only in the above-ground part of all types of grasslands except for the Zoysia japonica community, and there is almost no temperature rise at all three measurement points in the underground part. From this, it is presumed that even if the fire is turned on during the dormant period of the plants in early spring, only the dead leaves and dead stem on the ground are burned, and many living shoots under the ground are not affected. In other words, plants that originally lived in semi-natural grasslands, especially those capable of vegetative propagation, can be regenerated

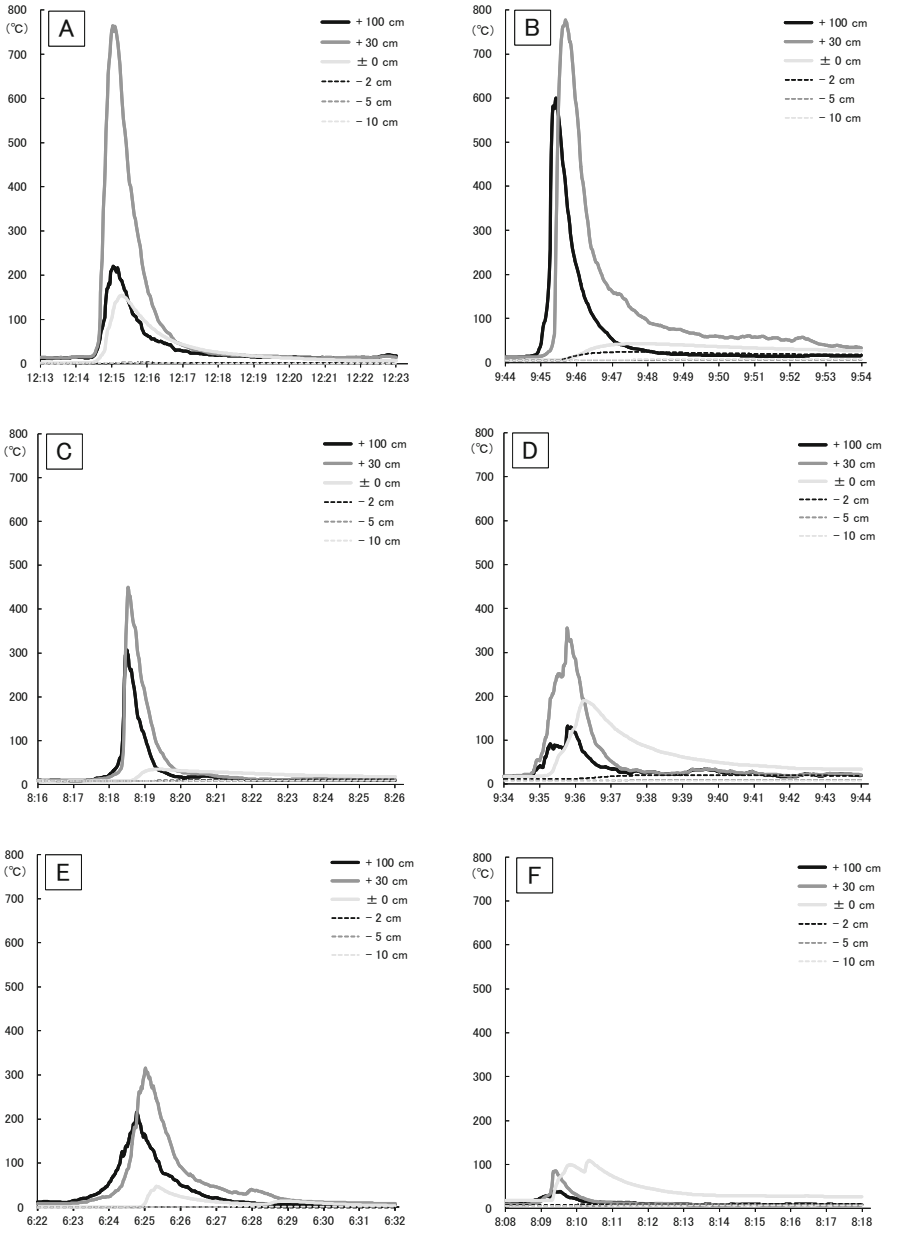

Fig. 5.2 Measurement results of temperature changes by height (+100, +30, ± 0, −2, −5, −10 cm) for 10 min when burning in different grassland types. A: Burning on Janurary 23, 2011 in the Phragmites australis community of the Sugao Marsh, B: Burning on February 8, 2020 in the Miscanthus sacchariflorus community of the Asahata Yusuichi (Drainage basin), C: Burning on April 20, 2019 in the Miscanthus sinensis community in the Mt. Kanpu, D: Burning on May 3, 2019 in the Miscanthus intermedius community in the Tonyu Bracken-Field, E: Burning on April 20, 2010 in the Leymus mollis community in the Koshimizu Gensei-Kaen, F: Burning on April 13 in the Zoysia japonica community in the Mt. Kanpu

from sprouts that survived by the summer of the year, even if they were burned in early spring. Since many species of the components of the semi-natural grassland are vegetatively regenerating species, they do not die even after burning, so the vegetation after burning has almost no structural change compared to the vegetation of the previous year.

Regarding seed germinating species, it is generally known that some Fabaceae species have seeds whose germination rate increases when exposed to high temperatures (Iwata 1966; Martin et al. 1975; Takahashi and Kikuchi 1986; Auld and O'Connell 1991, etc.). There are many *Lespedeza* species such as *Lespedeza bicolor* and *Lespedeza cyrtobotrya* in the *Miscanthus* type semi-natural grassland, and they may germinate due to heat.

5.4 Soil Temperature After Burning

Even if exposed to high temperatures during burning, the effect on vegetative regeneration plants with buds below the ground surface is relatively small. If the seeds are above ground, they may burn to death, but if they are buried underground, they are less likely to die from heat. Conversely, high temperatures during burning can promote seed germination. It is thought that not only heating during burning but also increase in soil temperature due to direct sunlight after burning affects seed germination. Masui et al. (2020) measured the soil temperature after burning in some semi-natural grasslands in eastern Japan and showed that the temperature during the daytime was higher than in unburned grasslands. They predicted that direct sunlight would warm the surface of the soil as a result of lack of litters in the burned grasslands, and the presence of litters in the unburned grasslands would prevent light heating. Figure 5.3 shows changes in soil temperature. Maximum soil temperatures at a depth of 0.5 cm were recorded at 31.9 °C and 28.2 °C on the afternoon of July 27 in burned and unburned grasslands, respectively, and 28.0 °C and 26.5 °C were recorded even at 2 cm underground.

The largest difference in soil temperature between burned and unburned grassland was reached at 12.1 °C (0.5 cm depth) and 7.9 °C (2 cm depth), in the afternoon of May 27. At this time, the soil temperature of the burned grassland was 22.3 °C at a depth of 0.5 cm and 17.2 °C at a depth of 2 cm, which was considerably higher than that of the unburned. Since the germination season of many plants in Japan is spring, it is expected that more plants will be able to germinate in the burned grassland where the soil temperature rises after burning. As Masui et al. (2020) predicted, if the presence of litter blocks sunlight and the soil temperature in the unburned area is lower than that in the burned area, there should be a difference in the amount of litter after burning. In fact, there is a few litter immediately after burning in burned area compared with unburned area of the Koshimizu Gensei-Kaen (Table 5.1).

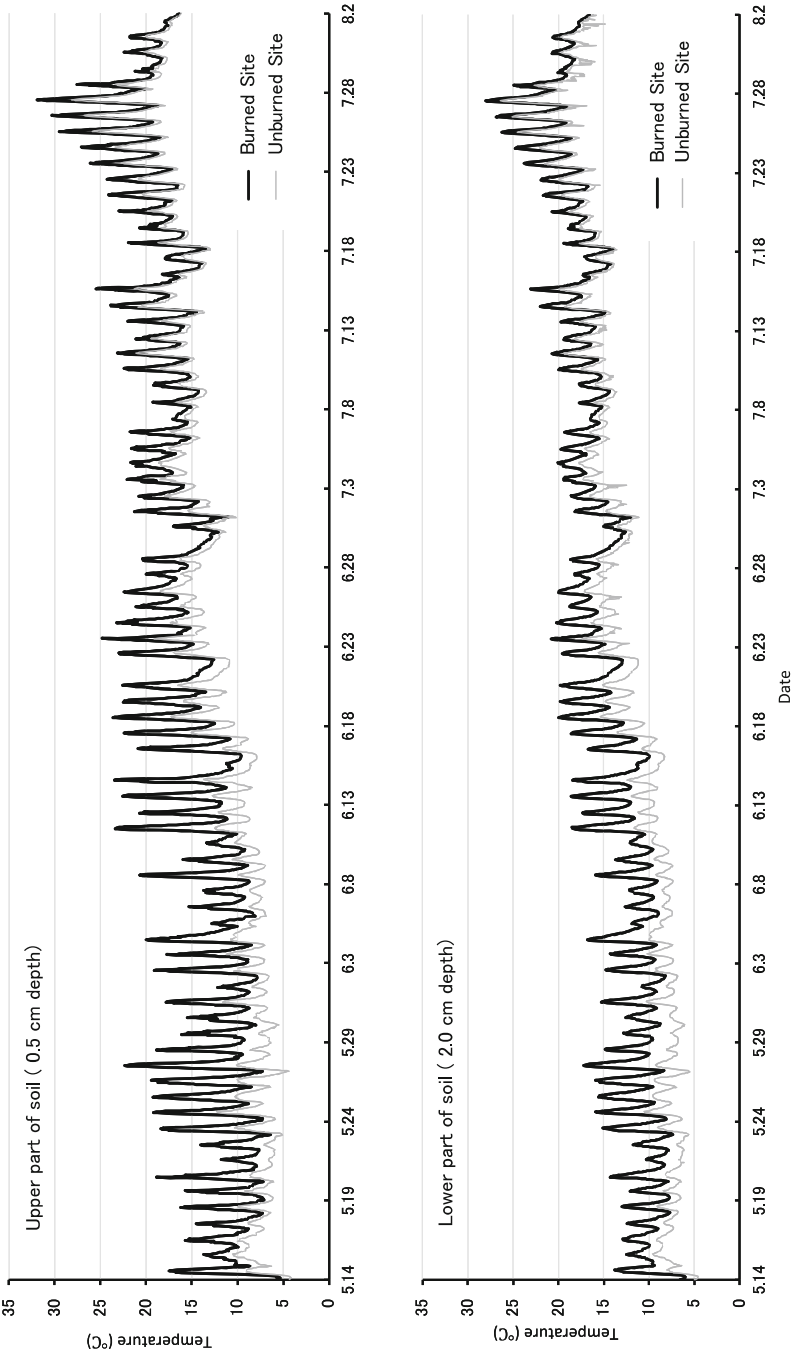

Fig. 5.3 Fluctuations of upper (−0.5 cm) and lower (−2.0 cm) soil temperature in the burned and unburned sites, in coastal grassland of Koshimizu Gensei-Kaen burned on May 13, 1997

Table 5.1 Annual change in the amount of litter in Koshimizu Gensei-Kaen

Sampling time	Fuel weight (g/m^2)	n
Just before burning	979.6 ± 282.9	25
Just after burning	202.1 ± 178.9	22
One year after burning	569.8 ± 184.5	22
Two years after burning	788.3 ± 166.1	22
Three years after burning	893.3 ± 334.4	22

Grassland burning is carried out in spring at intervals of about 5 years in Koshimizu Gensei-Kaen. One square meter of litter was collected from grasslands that had been burned for different year

Table 5.2 Vegetation structure and diversity index in burned and unburned areas of Miscanthus type seminatural grasslands in Mt. Kanpu

	Total number of species	Number of research quadrats (1 × 1 m)	Average number of species in one quadrats	Individual density (m^{-2})		Diversity index (H′)
				Vegetative shoots	Seed germination	
Burned site	61	13	22.08	436.77	67.77	2.82
Unburned site	57	9	17.33	286.75	4.33	2.59

5.5 Characteristics of the Plant Community After Burning

Seedlings are expected to increase due to the high temperature during burning or the rise in soil temperature after burning. Diversity can increase as seedlings are added to grassland vegetation. Table 5.2 shows the results of examining vegetation in the burned and unburned areas of Miscanthus sinensis Type grassland in Mt. Kanpu. Grassland burnings were carried out five times between 2008 and 2021, and some 1 × 1 m quadrat were set up in the summer for vegetation research in the semi-natural grassland. The number of individuals for each species in the quadrat were counted after separating seedlings and vegetative suprouts.

Although the number of research quadrats is slightly different, the total number of species appearing in the burned and unburned areas was 61 and 57, respectively. There was little difference in these numbers, but only 46 of them appeared in both burned and unburned areas. Fifteen species such as *Themeda barbata*, *Patrinia villosa*, and *Erigeron thunbergii* subsp. *thunbergii* appeared only in the burned area, and 11 species such as *Aster iinumae* and *Viburnum dilatatum* appeared only in the unburned area. The number of species and the density of individuals appearing in quadrat were higher in the burned area than in the unburned area. In the burned area, the density of vegetative sprouts increased to 1.5 times that of the unburned area, and the density of seedlings reached more than 15 times that of the unburned area. It is clear that the seed germination was promoted by burning. However the reason why the number of vegetatively regenerated individuals increased in the burned area is currently unknown.

In the study of the semi-natural grasslands of Mt. Kanpu, the total number of species that appeared was not so different between the burned and unburned areas, but the population density increased in the burned areas. In particular, a remarkable increase was observed in seed germinated individuals. If grassland burning is not carried out, vegetatively regenerating individuals will play a major role in maintaining the semi-natural grassland in Japan. Many seedlings appear when grassland burning is carried out, and it is expected that the semi-natural grassland will be composed of many plants. When the diversity index was calculated, it was $H' = 2.59$ in the unburned area, while it was as high as $H' = 2.82$ in the burned area.

5.6 Conclusion

Semi-natural grasslands in Japan are generally burned during the plant dormant period from winter to spring. High temperatures occur during burning, but the lethal temperature of plants is reached only in the above-ground parts, and the underground temperature does not rise. For dormant plants, the shoots and buried seeds below the ground surface are alive, but the above-ground parts are dead. Therefor even if they are burned, the effect of burning for plants is small. On the other hand, the soil temperature after burning becomes higher than the underground temperature during burning due to blackening with charcoal and irradiation with direct sunlight. Seedlings do not appear much in unburned area, but in burned area, seed germination is promoted and many seedlings appear in spring. As a result, highly diverse plant communities are maintained by burning in semi-natural grasslands in Japan.

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