Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 6, No. 5, p. 311-318, 2015
http://www.innspub.net

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RESEARCH PAPER OPEN ACCESS

The effects of fire on density, diversity and richness of soil seed bank in semi-arid rangelands of central Zagros region, Iran

Ali Asghar Naghipour[1*], Seyed Jamaleddin Khajeddin[1], Hossein Bashari[1], Majid Iravani[1], Pejman Tahmasebi[2]

[1]*Department of Natural Resources, Isfahan University of Technology, Isfahan 84156-83111, Iran;*
[2]*Faculty of Natural Resources and Earth Science, Shahrekord University, Sharekord 88186-34141, Iran*

Article published on May 23, 2015

Key words: Soil seed bank dynamics, Vegetation restoration, Diversity, Similarity.

Abstract

Soil seed banks can play an important role in vegetation restoration after large scale disturbances, particularly after disturbances (e.g. fire) that create gaps in the vegetation structure. It examined the effect of fire on soil seed bank dynamics of Central Zagros rangelands in semi-arid region of Iran by analysis of seed content in sample layers at depths of 0–5 cm and 5–10 cm. The seedling emergence method was used to determine species composition of the seed bank. The results indicated that no significant change was evident in the species richness and diversity of the germinable soil seed bank, but the density of the germinable soil seed bank differed significantly among burned and unburned (control) sites. Similarity between the vegetation and the seed bank was low and no significant was observed in the similarity between the soil seed bank and above ground vegetation in fire with control sites. In the upper soil layer (0-5 cm), fire produced a significance decrease of density. In the lower layer (5-10 cm) the seed bank showed no significant effects of fire thus confirming the role of soil depth to reduce fire impact.

***Corresponding Author:** Ali Asghar Naghipour ✉ aa_naghipour@yahoo.com

Introduction

Most plant species have the capacity to produce seeds that remain dormant in the soil for many years (Zhang and Chu, 2013). The mature viable seed reserves that are present in the soil or on the soil surface form the soil seed banks (Baskin and Baskin, 2001; Saatkamp *et al.,* 2014). The composition of the seed bank depends on the composition and production of the present and previous communities (Ma *et al.,* 2010; Snyman, 2005) as well as on the longevity of the seeds of each plant species under local conditions (Bekker *et al.,* 1997). The dynamic of soil seed bank is complex, and the rate and the size of turnover of the soil seed bank of a species depend on the balance between seed production, dispersal movements, pathogenesis, predation, viability, dormancy and germination, and on the variability of these factors at temporal and spatial scales (Galíndez *et al.,* 2013; Sternberg *et al.,* 2003). As soil seed banks could provide new seedlings to re-establish plant communities after disturbances (Snyman, 2005, 2013), natural regeneration mainly depends on the soil seed banks (Ma *et al.,* 2010; Saatkamp *et al.,* 2014).

Soil seed banks can play an important role in vegetation restoration after large scale disturbances (Solomon *et al.,* 2006; Thompson, 2000), particularly after disturbances (e.g. fire) that create gaps in the vegetation structure (Snyman, 2005; Thompson, 2000). The effect of fire on the soil seed bank depends on the species germination cues and the seed location in the soil profile (Wright and Clarke, 2009). Furthermore, high temperatures during fires may either stimulate seed germination or may have lethal effects, depending on the plant species (Paula and Pausas, 2008). Moreover, fire may affect moisture and thermal soil regimes and light conditions and the heat may destroy allelopathic compounds that inhibit germination (Zedler, 2007). Fire is a key disturbance in many ecosystems, and many studies have examined the role of the soil seed bank in the recovery of plant communities after fire (Dalgleish and Hartnett, 2009; Esque *et al.,* 2010; Keyser *et al.,* 2012; Morgan and Lunt, 1999), finding from decreases to increases in the soil seed bank size, dependent on the plant species and temperatures reached in the soil.

Fire is among the most important disturbances in central Zagros, and during the last decades, central Zagros rangelands have withstood large changes due to the severe use of fire (Tahmasebi and Askari, 2013). However, there are limited studies about the effects of fire on soil seed bank dynamic in Irano-Toranian semi-arid rangelands. In this region, fires are almost exclusively caused by humans, and occur during the dry summer and autumn months (Tahmasebi *et al.,* 2011).

The aims were to determine the fire effects on the soil seed bank and the role of seed bank in post-fire vegetation recovery and in the maintenance of community richness and diversity. It studied the seed bank dynamics during five years, and evaluated the similarity between species composition of seed bank and vegetation. Moreover, it analyzed the functional groups seed bank dynamics. This study provides valuable information about the effects of fire on the soil seed bank in Zagros rangelands where anthropogenic activities such as overgrazing, man-made fire and erosion are having significant impacts. This information will assist range managers in understanding the vegetation dynamics of plant species in response to fire. Furthermore, the general approach of this study could be applied to other semi-arid rangelands for identifying the effects of fire on soil seed bank; hence managers can take an informed decision about their management practices and avoid possible undesirable hazards.

Materials and methods

Study area

This study was conducted in Central Zagros rangelands which is located in semi-arid region of Iran (latitude: 33°4' N, longitude: 50°9' E and elevation 1770–3990 m above sea level). The long-term mean annual temperature and annual precipitation are 10.3°C and 336 mm, respectively (Daran Weather Station). Differences in geological substrate and topography further contribute to diversity of vegetation types in the region. The rangelands are dominated by the shrubs *Astragalus adscendens, Astragalus susianus* and *Astragalus verus*. The dominant perennial grasses are *Bromus tomentellus* and *Agropyron intermedium*. The quantity of fire events has increased dramatically in this semi-steppe rangeland system and results in patches of burned (with areas up to 100 ha) and unburned areas. They are generally followed by scrub encroachment and a strongly increasing human population during the last 50 years (Tahmasebi and Askari, 2013). Different parts of the study area (12 sites) were selected with known differences in dates since the last fire event (1 and 5 years). In order to inspect the shifts in plant communities and soil seed bank, unburned areas in close proximity to each treatment were chosen. Sits from different fire-years were matched on the basis of soil type, aspect, elevation and vegetation structure and composition.

Vegetation and soil seed bank sampling

Sampling of vegetation was conducted in spring 2013 and was stratified random sampling. Ten plots (2×2m) were installed in each site and its control in which the cover of plant species was estimated. Furthermore, the cover of different life forms including perennial grass, annual grass, annual forb, perennial forb and shrub were measured in each plot. Also, soil samples were collected in autumn 2013 after most species had completed fruiting and had released seeds. Since the majority of viable seeds were normally concentrated in the first ten centimeters of the ground (Zhang and Chu, 2013), soils were sampled in the quadrats with soil cores at the depths of 0–5 cm and 5–10 cm to yield a total volume of 600 cm^3. Altogether, 480 soil samples were collected. Soil samples were then sorted to eliminate plant fragments and stones, and kept in polythene bags before the experiment of seedling emergence.

Seed emergence technique

The density and composition of the seed bank were determined by seedling emergence method which was used to determine the abundance and distribution of viable seeds that could germinate under field conditions (Thompson, 2000). Samples were sieved through a sieve (4 mm) to remove roots and small stones. Remaining soil was spread to a depth of 1 cm in pots containing sterilized potting soil covered with a 0.5–1.0 cm layer of pure silica sand. The pots (A total of 480 pots) were placed in a completely randomized design in a greenhouse (27°C at day, 15°C at night) for 6 months. To quantify germination of seeds blown onto the experimental pots, 64 control pots were also placed randomly. All pots were watered as necessary, with emerged seedlings identified, counted and removed. Seedlings that cannot be identified would be individually transplanted to big pots to allow growth and flowering for further confirmation. Seed germination was discontinued when no further seedling emergence was recorded for one month.

Statistical analyses

To characterize the seed bank of each site as a whole, the mean species richness, mean seed density (seeds m^{-2}), and mean species diversity from all quadrats within one site were calculated. The Shannon index was used to assess species diversity for inter-site comparison. Shannon diversity index (H) was used to calculate the diversity index of the seed species at each site (Magurran, 2013). Sørenson's index of similarity (Sørensen, 1948) was used to calculate the floristic similarity between seed bank and above ground vegetation. Sørenson similarity= 2w/(A+B), where A= the number of species aboveground, B= the number of species belowground, and w= the number of species found both above and belowground. The Sørenson's index was chosen because it is simple, effective, and widely used (Magurran, 2013). The data sets were analysed by one-way analysis of variance (ANOVA) to determine the effects of the fire on soil seed bank. Data normality and homoscedasticity were tested using the Kolmogorov-Smirnov test (Lilliefors,

1967) and Levene's test (Levene, 1960), respectively, prior to analysis. Data were log-transformed when normality assumptions were not met. Tukey's Honestly Significant Difference (HSD) was analysed whenever appropriate ($P<0.05$). All statistical analyses were performed using the SPSS 16 (©SPSS Inc., 1989–2007).

Results and discussion

General description of the soil seed bank

A total of 1333 seedlings from 46 species germinated during the study, which belonged to 17 families and 39 genera. This corresponded to a mean of 936 seeds m^{-2}, with a mean richness of 13.7 species per site. Of these, forbs comprised the largest group, with just over 76% of the total species (35 species). Grasses were the next most abundant group (21.7%), while woody plants only 0.02% of the total species (1 species). Our results showed a significant correlation in seed density and species richness with depth (Table 1). Overall species and seed numbers were lower in the lower layer (5-10 cm) than in the upper layer (0-5 cm), which was consistent with other studies (Esposito *et al.,* 2006; Jalili *et al.,* 2003; Zhang and Chu, 2013). In the upper soil layer (0-5 cm), fire produced a significant decrease of density. In the lower layer (5-10 cm) the seed bank showed no significance effects of fire, thus confirming the role of soil depth to reduce fire impact and that the effects of fire impact mediated by soil depth was differently affecting species composition because of their various vertical distribution of seed in the soil (Esposito *et al.,* 2006). Most species in the seed bank were found in low numbers, while the 10 most abundant species encompassed about 82 percent of all individuals (Table 2).

Table 1. Species number and germinable seed density of soil seed bank.

Dates since the last fire	Treatment	0-5 cm		5-10 cm	
		Number of species (1 SE)	Number of viable seeds / m^2 (1 SE)	Number of species (1 SE)	Number of viable seeds / m^2 (1 SE)
1 year	Fire	8.3 (1.1)	521.3 (47.2)	3.5 (0.7)	107.6 (16.2)
	Control	9.3 (0.7)	1127.6 (142.3)	4.5 (0.7)	116.2 (10.2)
5 year	Fire	10.3 (1.1)	716.8 (67.1)	4.8 (0.7)	119.0 (21.9)
	Control	9.6 (0.5)	943.5 (82.4)	4.3 (0.4)	124.6 (23.1)

Table 2. The 10 most common plant species s in the germinable soil seed bank at the site, with details of family, life from, mean density and percent contribution to the total germinable seed bank density.

Species	Family	Life form	total seed numbers per m^2 (1 SE)		Percent contribution to density	
			Fire	Control	Fire	Control
Bromus tomentellus Boiss.	Poaceae	PG	99.1 (18.2) b	349.9 (44.4) a	13.5	30.3
Poa bulbosa L.	Poaceae	PG	104.8 (39.3)	174.2 (90.8)	14.3	15.1
Drabopsis verna K. Koch.	Brassicaceae	AF	103.4 (39.3)	93.5 (32.0)	14.1	8.1
Ceratocephalus falcatus (L.) pers.	Ranunculaceae	AF	32.6 (9.4)b	109.1 (21.0)a	4.5	9.4
Bromus tectorum L.	Poaceae	AG	35.4 (10.9)b	86.4 (20.3)a	4.8	7.5
Holosteum umbellatum L.	Caryophyllaceae	AF	45.3 (15.3)	42.5 (9.7)	6.2	3.7
Bromus danthoniae Trin. ex C.A.Mey.	Poaceae	AG	32.6 (15.3)	38.2 (14.8)	4.5	3.3
Eremopoa persica (Trin.) Roshev.	Poaceae	AG	45.3 (42.2)	24.1 (10.5)	6.2	2.1
Boissiera squarrosa (Sol.) Nevski	Poaceae	AG	35.4 (10.3)	26.9 (12.5)	4.8	2.3
Hypecoum pendulum L.	Papaveraceae	AF	34.0 (12.7)	25.5 (13.5)	4.6	2.2

PG: Perennial Grass; AG: Annual Grass; AF: Annual Forb.

Soil seed bank density, richness and diversity

The effect of fire on soil seed bank was shown in Fig. 1. The number of seeds per 1 m² was significantly higher in unburned (control) sites than in burned sites (Fig. 1). The reduction in the soil seed bank under fire may be due to negative effect of fire on seeds of many species, especially those which are not fire-tolerant. Since burning occurs in dry season, higher fire intensity was expected to impact seed bank due to high temperature caused by fire as explained by Esposito *et al.* (2006). This result is in line with Laterra *et al.* (2006); MARTÍNEZ-OREA *et al.* (2010) who reported that burning reduces the amount of live seeds on the seed bank.

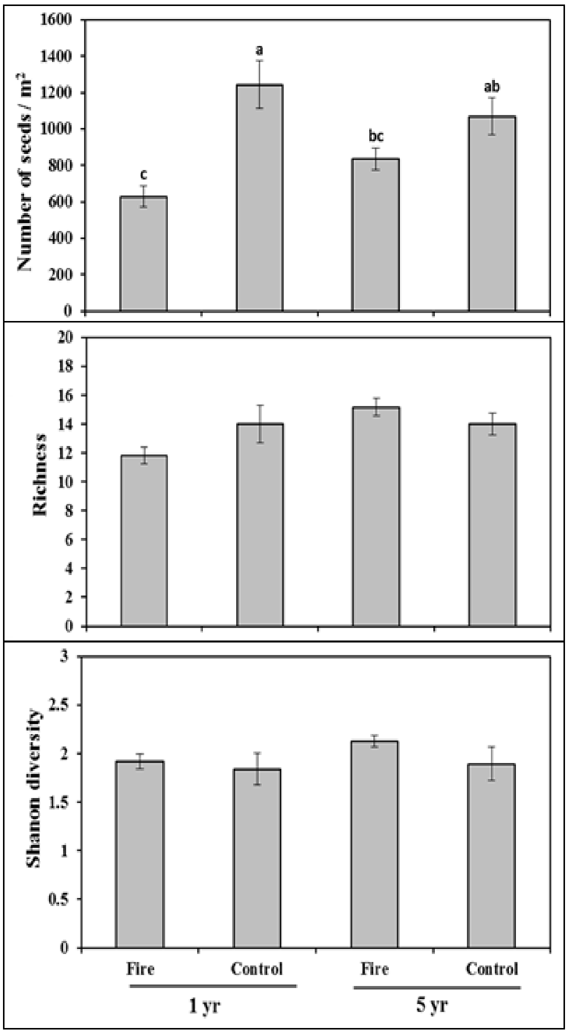

Fig. 1. Seed density, richness and diversity of soil seed banks at 0–10 cm(total) depths among fire and control. Means with a different letter differ at $p < 0.05$ (Tukey's test). Error bars show the standard error of the mean.

Shannon index was determined from the soil seed bank composition at each site (Fig. 1). No significant change was evident in the species richness and diversity of the germinable soil seed bank among burned and unburned (control) sites. Species richness and diversity of the germinable soil seed bank were not significantly correlated with time since fire, which concurs with other studies undertaken in a range of systems and disturbance types (Wills and Read, 2007). However, this finding is contrary to our predictions.

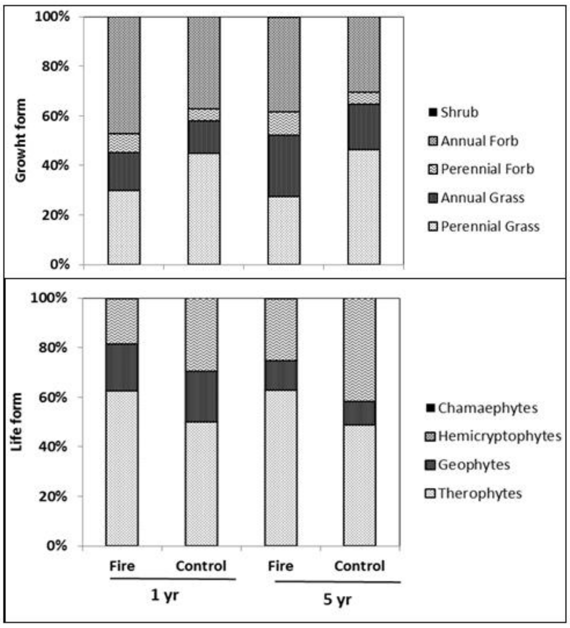

Fig. 2. Percentage of species in the soil seed bank (0–10 cm) for fire (burned) and control (unburned) sites according to growth forms and life forms.

Therophytes were the most frequent life form in both unburned and burned areas (Fig. 2). In all the treatments, chamaephytes and phanerophytes are rare if not existing. After fire there was a change in the ratio of the initial proportion between therophytes and hemicryptophytes which was practically the reverse: the proportion shifted from 50% therophytes and 30% hemicryptophytes in the control, to 62% therophytes and 18% hemicryptophytes respectively one years after fire and to 63% therophytes and 25% hemicryptophytes respectively five years after fire. Perennial grasses are abundant in unburned areas (control) and are less frequent in burned areas (Ma *et al.*, 2010). This is consistent with our results: in vegetation as well as seed bank, the proportion of perennial species decreased with fire (Fig. 2).

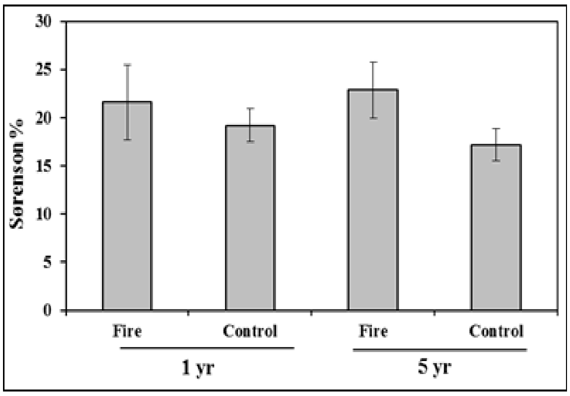

Fig. 3. Sørenson's index of similarity (%) between soil seed bank and above ground vegetation.

Relationship between soil seed bank and vegetation

A total of 155 species was identified in the vegetation and soil seed banks at the study sites, and 22.6% of these species occurred in both the seed bank and the vegetation; 7.1% and 70.3% were only in the soil seed bank or in the vegetation, respectively. It recorded 109 plant species in above ground vegetation that were not represented in the soil seed bank. Also, eleven species were found in the soil seed bank but not as adult plants in the vegetation. The presence of a species in the seed bank but not in the vegetation could be a consequence of seed dispersal from adjacent areas or of seed persistence in the soil after the death of an adult plant (Esmailzadeh *et al.,* 2011).

The similarity between soil seed bank and above ground vegetation was low for sites, with joint presences giving a Sørenson similarity of 17.2 to 22.8%. In addition to, no significance was observed in the similarity between the soil seed bank and above ground vegetation in fire with control sits (Fig. 3). Rangelands predominated by shrubs and perennial grasses have few similarities between vegetation and soil seed bank (Wills and Read, 2007; Zhang and Chu, 2013). The results indicated that there was no close relationship between the composition of the soil seed bank and that of the aboveground. This poor correspondence between vegetation and soil seed bank is attributed to lack of dormancy mechanisms and to ability of non-dormant seeds of many woody species to germinate (Baskin and Baskin, 2001). Also, seeds of woody species are not abundant in soils because they generally have a transient or short-lived seed bank (Baskin and Baskin, 2001; Thompson, 2000). Lack of a persistent seed bank explains why tree species like *Astragalus adscendens, Astragalus susianus* and *Astragalus verus* were not represented in the seed bank and why there were no seedlings of any other woody species germinated in the soil samples. Such dissimilarity could also be influenced by seed dispersal from outside the community, where plant species are detected within the soil seed bank but not in the above ground vegetation (Thompson, 2000).

Conclusion

An understanding of soil seed bank dynamics is crucial for understanding vegetation dynamics, particularly in ecosystems experiencing frequent disturbance. The results indicate that fires can influence seed bank dynamics. Species composition, abundance of seeds in the seed bank, seed ecology of the species under investigation, and floristic similarity between seed banks and aboveground vegetation are important clues to the possible contribution of the soil seed banks to regeneration processes (Tekle and Bekele, 2000).

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