ECOLOGIA BALKANICA

2014, Vol. 6, Issue 1 June 2014 pp. 61-71

Effects of Drought on Plant Species Diversity and Productivity in the Oak Forests of Western Iran

Hassan Pourbabaei, Verya Rahimi, Mohammad Naghi Adel*

Department of Forestry, Natural Resources Faculty, University of Guilan,
Somehsara, P. O. Box 1144, Guilan, IRAN
* Corresponding author: mn.adel87@gmail.com

Abstract. A severe drought in 2008 extensively damaged a variety of economic, social, agricultural and natural resources in Iran. This study investigated the effects of the 2008 drought on plant species composition, diversity and productivity in Western Iran. To this end, plant species diversity in the drought year (2008) was compared to pre-drought (2007) and post-drought (2009) diversity. The Shannon-Wiener diversity index and Margalef richness index had significant differences between years, decreasing significantly during drought and significantly increasing post-drought. In contrast, the Smith-Wilson evenness index did not significantly differ between years. Plant dry weight was significantly reduced by drought and increased significantly post-drought. The percent cover of sixteen species was significantly reduced in the drought year. Furthermore, nine species disappeared during drought, but reappeared after precipitation. The most sensitive species to drought were *Psathyrostachys fragili, Carex sp., Falcaria falcarioide, Festuca ovina* and *Scariola orientalis.* Five species *(Cardaria draba, Echium amoenum, Polygonatum orientale, Medicago noeana* and *Cirsium vulgare)* not present before and during drought appeared the year after drought ended. Some of the effects of drought may be reduced by improved land management planning and water conservation to better provide for the water needs of Iran and other drought-prone countries.

Keywords: Drought, Precipitation, Plant Diversity, Productivity, Western Iran.

Introduction

Water availability is the primary limitation to plant productivity in many terrestrial biomes and it is an ecosystem driver that will be strongly affected in many areas of the world by ongoing and future climate change (HEISLER-WHITE *et al.*, 2008). Recent climate models predict that the 21st century will be characterized by increasing temperatures, changing precipitation patterns and more frequent extreme events such as heat waves and droughts (SCHAR *et al.*, 2004) that will exacerbate land degradation and desertification (MEADOWS & HOFFMAN, 2003). Drought-related ecological degradation, including forest dieback, grassland desertification, wetland degradation, and Lake Desiccation have been widely reported, especially in semi-arid regions (YIN *et al.*, 2012).

Ecological vulnerability to climate change depends on the ability of natural ecosystems to cope with stresses to biological systems (SCHROTER *et al.*, 2005). One anticipated effect of climate change is expected to be loss of species (IPCC, 2001). Drought has major impacts on the composition, structure and function of vegetation (ALLENA *et al.*, 2010). Drought can inhibit photosynthesis, cause mortality, create conditions for outbreaks of plant diseases and insect pests, and increase the

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frequency and intensity of fire disturbance. Cumulatively, these factors can alter plant communities, causing extensive mortality potentially endangering survival of some plant populations and lowering total primary productivity of terrestrial ecosystems, accelerating the loss of ecosystems in fragile areas, and even endangering regional biodiversity (WANG *et al.*, 2010). There are three ways which plants may respond to a climatic change: persistence in the modified climate, migration to more suitable climates, or extinction (THEURILLAT & GUISAN, 2001). This study documents the response of an arid ecosystem in western Iran to a severe drought.

Climatic variability is a prominent feature of most ecosystems (HENDERSON-SELLERS & ROBINSON, 1991). Semiarid regions seem to be susceptible to drought (ALLEN & BRESHEARS, 1998). According to the United Nations (provide reference here), in the near future, 31 countries will experience serious water shortages, with Iran one of the most sensitive jurisdictions. UN research suggests that available water in 1990 of 2000 million m^3 will be reduced to 726-860 million m^3 in 2025 in Iran. Iran is the eighteenth largest country in the world, with an area of 1,648,195 km2. Iran has arid to semi-arid climate with low rainfall. Surface and subsurface water flow into Iran are very low. The main source of water is rainfall, which has an annual average of 250 mm. This amount is one-third of world and Asian rainfall. Furthermore, regionally, northern Iran receives annual average precipitation of 850 mm, while other parts of the country receive less than 50 mm.

Drought occurs somewhere in Iran almost every year. Despite the importance of drought and rainfall to Iran, its effects have only been studied in the agricultural and economic sectors, with no attention to natural resources, such as forests, that are important for forage and in preventing desertification. The aim of this study was to investigate the effects of drought on plant species composition, diversity and productivity in western Iranian forests. It is hoped that this research will lead to more attention on climate change and its effects on the vegetation of Iran.

Material and Methods

Study area

The study area (10000 ha) is located in the forests of Divandarreh, a city in Kurdistan province in western Iran (35°54′50″ N, 47°01′26″ E). Divandarreh is located in the Zagros Mountains of northern Kurdistan. The average altitude is 1850 m a.s.l. Annual temperature varies between -20 to +32 °C. The mean temperature of the warmest month of the year is 23.3 ° C and the mean temperature of the coldest month of the year is -7.3° C. The number of frost days is 135 per year. Average annual precipitation is 350 to 450 mm. Soils range in pH from 6.2 to 6.7. A severe drought occurred in 2008. Table 1 shows annual precipitation average in the 2007, 2008 and 2009 years for the nearest meteorology station (Fig. 1).

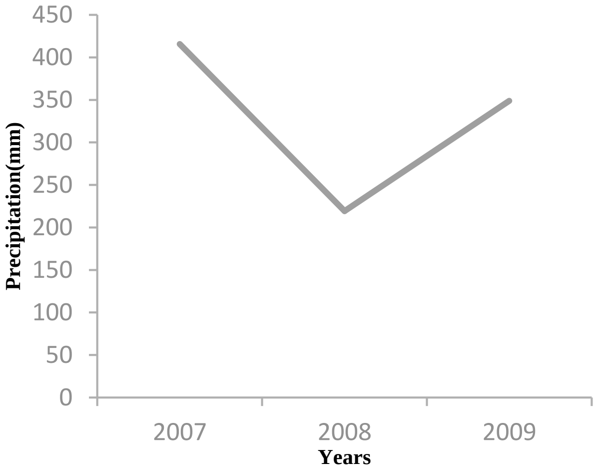

Fig.1. Total annual precipitation in the study area

Sample collection

Vegetation in 2007, 2008, and 2009 (pre-drought, drought, and post-drought years, respectively) was analyzed. The area sampled was determined using Whitaker's minimal area (POURBABAEI & POURRAHMATI, 2009), resulting in plants being analyzed on 64 m^2. Data collection was based on the Domin criterion (POURBABAEI & POURRAHMATI, 2009). In each year 30-64 m^2 sample plots were assessed. Plants were segregated by species and dry weights measured after oven-drying for 72 hours at 75°C.

Data Analysis

To evaluate the effect of drought and precipitation on different aspects of plant biodiversity, we used three indices. Species diversity was assessed with the Shannon-Wiener index (MAGURRAN, 1988):

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where P_i is the relative frequency of the ith species.

Species richness was estimated according to the Margalef index (LUDWIG & REYNOLDS, 1988):

$$R_{Mn} = \frac{S}{\sqrt{N}}$$

where S is the total number of species and N is the total number of individuals.

Species evenness was calculated using the Smith-Wilson index (SMITH & WILSON, 1996):

$$E_{var} = \frac{2}{\pi \arctan\left\{ \sum_{i=1}^{s} \left(\log_e(n_i) - \sum_{j=1}^{s} \log_e(n_j)/s)^2 \right) \Big/ S \right\}}$$

where n_i is the number of individuals of the ith species in a plot, n_j is number of individual of the jth species, and S is the total number of species in U and UB areas.

All three indices were computed with software provided by KREBS (1989; Ecological Methodology for Windows, version 6.0).

Kolmogorov–Smirnov tests were used to test normality of all parameters. The significance of difference between means was analyzed using one-way ANOVA, followed by Duncan's mean separation test at the 95% level. Statistical analyses were performed using SPSS (version 18.0, SPSS Inc., Chicago, USA).

Results

In total, 42 species belonging to 15 families were present. The most common families were *Fabaceae* (8 species), *Asteraceae* (7), *Poaceae* (6), *Umbelliferae* (5), *Lamiaceae* (4), *Liliaceae* (2). *Cyperaceae, Euphorbiaceae, Poaceae, Chenopodiaceae, Plantaginaceae, Polygonaceae, Papaveraceae* and *Boraginaceae* families were each represented by only one species.

Greatest percentage ground cover by species in 2007 was, in order, *Astragalus* sp, *Gundelia tourneforti, Euphorbia aucheri, Phlomis kurdica, Ferula haussknechtii* and *Trifolium resupinatum.* In the drought year, greatest ground cover was found to be *Astragalus* sp., *Phlomis kurdica* and *Stachys lavandulifolia.* In the post-drought year, ground cover changed again, with *Astragalus* sp., *followed by Eryngium caucasicu, Echinops haussknechtii, Gundelia tournefortii, Euphorbia aucheri, Phlomis kurdica, Onobrychis andalanica* and *Trifolium resupinatum*.

Astragalus sp., *Echinops haussknechti, Gundelia tournefortii, Euphorbia aucheri, Phlomis kurdica, Ferula haussknechtii, Cynodon dactylon, Onobrychis andalanica, Bromus tectorum ,Thymus kotschyanus, Tragopogon buphthalmoides, Vicia koeieana, Rheum ribes, Kelussia odoratissima, Allium hitifolium* and *Glaucium contortuplicatum* had significant decrease in production at the end of the drought year. *Astragalus* sp., *Eryngium caucasicum, Echinops haussknechtii, Euphorbia aucheri, Phlomis kurdica ،, Ferula haussknechtii, Cynodon dactylon, Onobrychis andalanica, Bromus tectorum, Thymus kotschyanus, Tragopogon buphthalmoides, Vicia koeieana, Rheum Ribes, Glaucium contortuplicatum, Allium hitifolium* and *Kelussia odoratissima* species had significant increase in precipitation year. *Heteranthelium piliferum, Dactylis glomerata, Stachys lavandulifolia, Cicer anatolicum, Agropyrum kosaninii* and *Achillea kellalensis* species had no significance difference between three years.

Anthemis persica, Poa pratensis, Lotus gebelia, Grammosciadium platycarpum, Mentha longifolia, Glycyrrhiza glabera, Plantago atrata, Rapistrum rugosum and *Trifolium resupinatum* species were not present in the drought year but were found both before and after the drought, in 2007 and 2009. *Psathyrostachys fragilis, Carex* sp., *Falcaria falcarioides, Festuca ovina* and

Scariola orientalis species were only present in 2007 and did not reappear in the year immediately following the drought. *Cardaria draba, Echium amoenum, Polygonatum orientale, Medicago noeana* and *Cirsium vulgare* species were only present in the year following drought (Table 1).

Table 1. Changes in percent cover in relation to severe drought conditions in the Kurdistan region of western Iran

	Species	Family	Pre drought (2007 year)	Drought (2008 year)	After drought (2009 year)
1	*Astragalus sp.*	Fabaceae	24.37ab	18.37b	28.14a
2	*Heteranthelium piliferum*	Poaceae	1.5a	1.12a	2a
3	*Eryngium caucasicum*	Apiaceae	3.57b	2.55b	10.33a
4	*Psathyrostachys Fragilis*	Poaceae	2.97	0	0
5	*Echinops Haussknechtii*	Asteraceae	3.46ab	1.75b	7.5a
6	*Gundelia Tournefortii*	Asteraceae	8.46a	3.42b	6.78ab
7	*Euphorbia aucheri*	Euphorbiaceae	13.9a	4.92b	9.78ab
8	*Carex sp.*	Cyperaceae	1.08a	0	0
9	*Anthemis persica*	Asteraceae	6.35a	0	6.31a
10	*Phlomis kurdica*	Lamiaceae	13.18b	5.57c	18.65a
11	*Ferula Haussknechtii*	Apiaceae	10.76a	2.38b	8.53a
12	*Cynodon dactylon*	Poaceae	1.83a	.375b	2.75a
13	*Poa pratensis*	Poaceae	3.66a	0	1.02b
14	*Onobrychis andalanica*	Fabaceae	6.62ab	3.63b	7.9a
15	*Dactylis glomerata*	Poaceae	1.75a	1.12a	1.46a
16	*Lotus Gebelia*	Fabaceae	2.12a	0	2.5a
17	*Bromus tectorum*	Poaceae	1.45ab	.53b	2.79a
18	*Thymus kotschyanus*	Lamiaceae	4.23a	.27b	4.36a
19	*Tragopogon buphthalmoides*	Asteraceae	4.01a	.4b	2.57a
20	*Stachys lavandulifolia*	Lamiaceae	5.3a	5.48a	5.04a
21	*Grammosciadium platycarpum*	Apiaceae	4.25a	0	2.33b
22	*Falcaria falcarioides*	Apiaceae	3.1a	0	0
23	*Cardaria draba*	Cruciferae	0	0	.375
24	*Cicer anatolicum*	Fabaceae	.84a	.58a	1.31a
25	*Festuca ovina*	Poaceae	1.62a	0	0
26	*Mentha longifolia*	Lamiaceae	1.87a	0	1a
27	*Agropyrum kosaninii*	Chenopodiaceae	3.05a	2.3a	3.14a
28	*Achillea kellalensis*	Asteraceae	6.44a	4.24a	4.26a
29	*Vicia koeieana*	Fabaceae	2.4a	.65b	3.9a
30	*Glycyrrhiza glabera*	Fabaceae	1.14a	0	1.05a
31	*Plantago atrata*	Plantaginaceae	.55a	0	.68a
32	*Rapistrum rugosum*	Cruciferae	6.47a	0	2.29b
33	*Trifolium resupinatum*	Fabaceae	9a	0	7.5a
34	*Rheum Ribes*	Polygonaceae	7.53a	.87b	5.61a
35	*Scariola orientalis*	Asteraceae	2.2a	0	0
36	*Glaucium contortuplicatum*	Papaveraceae	7.66a	.33b	4.28ab
37	*Allium hitifolium*	Liliaceae	4.01a	.65b	5.31a
38	*Kelussia odoratissima*	Apiaceae	3.08a	.25b	3.23a
39	*Echium amoenum*	Boraginaceae	0	0	2.37
40	*Polygonatum orientale*	Liliaceae	0	0	1.75
41	*Medicago noeana*	Fabaceae	0	0	6.26
42	*Cirsium vulgare*	Asteraceae	0	0	1.5

Plant diversity varied significantly due to drought as shown by the Shannon-Wiener diversity index and Margalef richness index. Diversity decreased significantly in 2008 (drought year) and had a significant increase in 2009. The Smith-Wilson evenness index had no significant difference between years. Production was significantly reduced in 2008 but in 2009 increased significantly (Fig. 2-5).

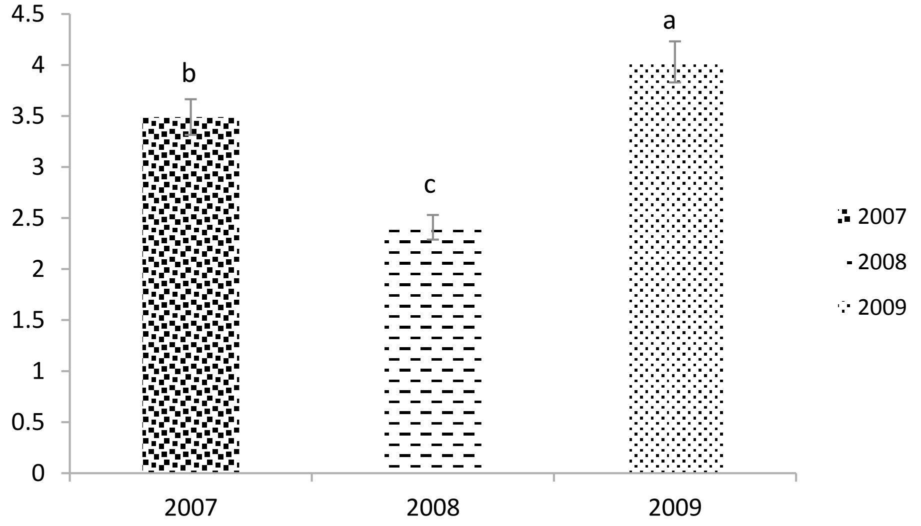

Fig.2. Margalef index measured before, during, and after a severe drought in 2008

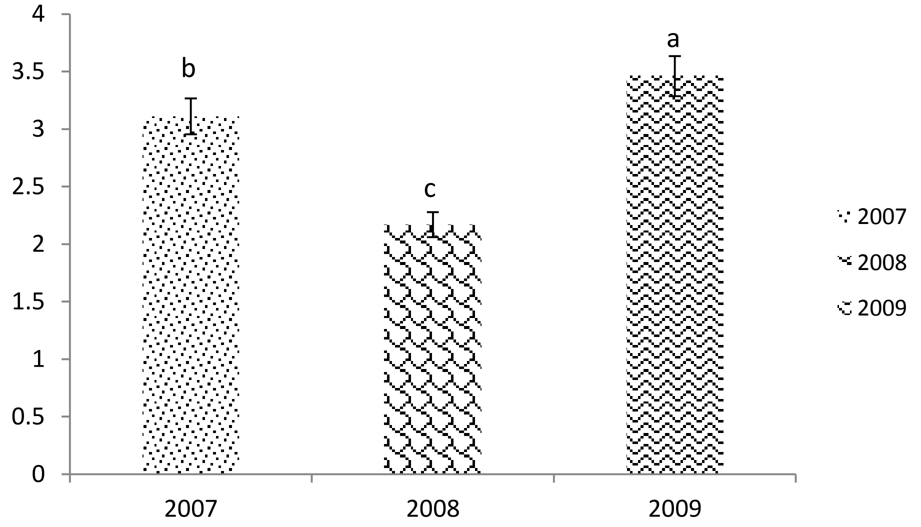

Fig.3. Shannon-Wiener index measured before, during, and after a severe drought in 2008

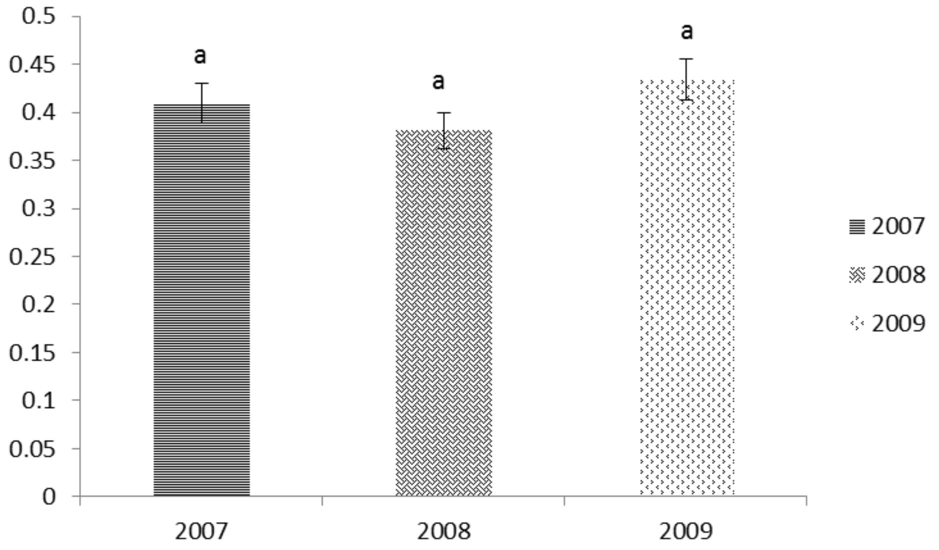

Fig.4. Smith- Wilson index measured before, during, and after a severe drought in 2008

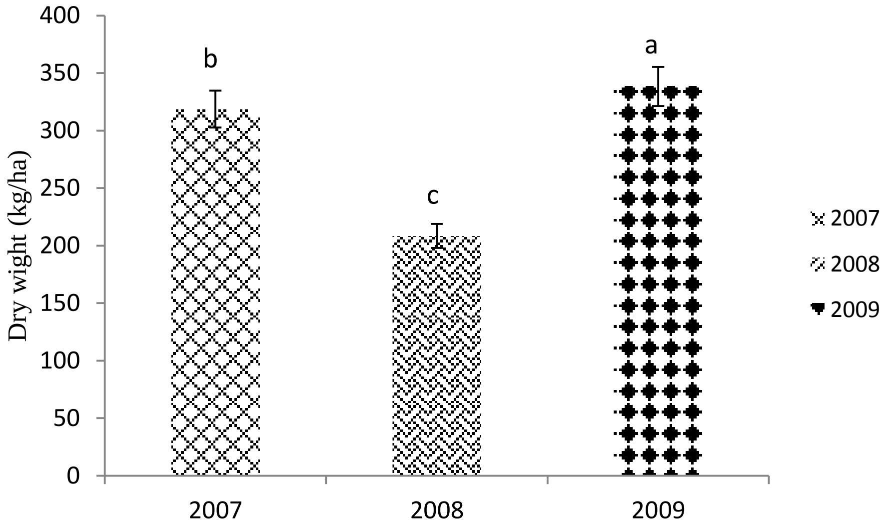

Fig.5. Dry weight (kg/ha) measured before, during, and after a severe drought in 2008

Discussion

Drought decreased species richness and diversity and reduced total plant ground cover. Drought affects many important plant processes, such as photosynthesis. Other studies had similar results (TILMAN & EL HADDI, 1992; HARTE & SHOW, 1995; KNAPP, 2002; MORECROFT, 2004; STAMPFLI & ZEITER; 2004; LLORET *et al*., 2009). As a direct consequence of drought, species composition might shift, productivity and reproduction could be reduced, and mortality increased (JENTSCH & BEIERKUHNLEIN, 2008). A possible indirect effect of drought could result from decreased vitality, making some species susceptible to damaging pathogens and insects (VOLNEY-LOUSTAU *et al*., 2006). Drought may also act indirectly through increased fire frequency, or by fires occurring where it was not previously common, affecting species poorly adapted to fire with significant negative ecosystem impacts. LINDNER (2010) found that areas at higher elevation could become drier and therefore more susceptible to fire, and might be a factor in the present study area, which is a high elevation site.

While elevated temperatures are expected to enhance soil fauna activity and decomposition rates, drought may counteract these effects or even lead to local extinction of some soil organisms (HULME, 2005). A strong link between herbaceous plant diversity and soil parameters associated with the availability of nutrients has indeed been reported in previous studies (RAMOVS & ROBERTS, 2003; CHUST *et al.*, 2006; MARKS *et al.*, 2008; BAI *et al.*, 2011). Drought may affect soils due to altered soil moisture and litter decomposition rates (LINDEDAM *et al.*, 2009). Drought in this region can indirectly affect species richness via altering soil water availability. Changes in soil moisture and temperature influenced processes such as litter decomposition, nutrient cycling, primary productivity, plant recruitment, survival, and the rate and direction of succession (COUTEAUX *et al.*, 1995).

Some of the effects of the 2008 drought observed in this study were transitory, with a significant recovery in species richness and diversity occurring in 2009. MATIAS *et al.*, (2011) showed that plant communities growing under wet conditions can have higher species richness and diversity. Other studies had similar results (STERNBERG *et al.*, 1999; ADLER & LEVINE, 2007; ZAVALETA, 2003; YANG *et al.*, 2011). As noted by SERENGIL *et al.* (2011), changes in precipitation and temperature in a region directly affect evapotranspiration, a key parameter in soil water budgets. Iran's arid to semi-arid climate means that water availability is one of the predominant limiting factors directly affect species richness by impacting the establishment and growth rates of species (BAZZAZ, 1996; NIU *et al.*, 2008). In comparison to species richness, drought and rainfall had no effect on species evenness. YANG *et al.* (2011) similarly found that drought and precipitation had no effect on species evenness.

Productivity was significantly reduced in the year of drought and increased the following year under more normal precipitation levels. It is well known that that precipitation increases plant production but drought decreases it (SALA *et al.*, 1988; BOLLINGER *et al.*, 1991; LAUENORTH & SALA, 1992; PARTON *et al.*, 1944; DHILLION & ANDERSON, 1994; KAHMEN *et al.*, 2005; VAN RUIJVEN & BERENDSE, 2010). BOLORTSETSEG & TUVAANSUREN (1996) showed that increased precipitation enhanced plant biomass and prolonged the growing season.

Drought significantly reduced ground cover of sixteen species. These species were more sensitive to water shortage with the result that their regional abundance could be largely diminished in the event of widespread, long-term drought. One of the effects of climate change on biodiversity is increasing vulnerability of species (VOS *et al.,* 2008). Plants on nutrient-poor sites are more likely to suffer nutritional deficiencies with drought as nutrient uptake is highly correlated with water availability (MILAD *et al.,* 2011). GILGEN & BUCHMANN (2009) concluded that sites with lower annual precipitation seem to be more vulnerable to drought than sites with higher annual precipitation.

Sixteen species significantly increased with increasing rainfall. Nine species disappeared during drought, but reappeared after precipitation. In fact, drought eliminated these species, but seed of these species that was present allowed them to return when moisture conditions improved.

The most drought sensitive species were *Psathyrostachys fragili, Carex sp, Falcaria falcarioide, Festuca ovina* and *Scariola orientalis*. The drought caused local extirpation of these species and by eliminating their seeds and they failed to reappear when the one-year drought ended. All species that were extirpated had low abundance prior to the drought. If species are not able to reach new suitable habitat and fail to adapt to changing conditions, range loss and species extirpation are possible (ENGLER *et al.,* 2009). Species with limited distributions are likely to be more prone to extinction due to climate change because gene flow between populations and colonization rates can be low (HAMRICK, 2004). BAKKENES *et al.*, (2006) concluded that future climate change will exacerbate the loss of species, especially those with strict climate and habitat requirements and limited migration capabilities. Environmentally extreme conditions such as severe drought enhance the probability of extinction of less abundant species (WHITE *et al*. 2000; LANTA *et al*., 2012). According to LLORET *et al*., (2004), species loss due to climatic alterations is related to species abundance, that is, less abundant species being more prone to disappear under drier conditions.

Cardaria draba, Echium amoenum, Polygonatum orientale, Medicago noeana and *Cirsium vulgare* species were not present before and during drought. Interestingly, drought provided an opportunity for these species to in-migrate from neighboring regions to successfully compete with existing species. Thus, while drought may affect current species composition, it appeared to also provide opportunities for plant migration, which may be an important natural mechanism to maintain net primary productivity and species diversity as the climate changes. Species which are unable to shift their range to higher altitudes are expected to be replaced as more competitive species are able to exploit higher elevations due to climate warming (VERBOOM *et al*., 2007). Entered species could affect ecosystems for example by competition, hybridization, diseases or altering habitats, culminating in extinction of some species and losses in biodiversity (HAMRICK, 2004).

Several species (*Heteranthelium piliferum, Dactylis glomerata, Stachys lavandulifolia, Cicer anatolicum, Aropyrum kosaninii* and *Achillea kellalensis*) were unaffected by either drought or drought recovery. This is believed due to the strong root systems of these species, enabling them to obtain water from deeper in the soil, and thereby avoid drought.

Conclusion

We document the reductions in plant species diversity and productivity in the forests of western Iran due to a severe regional drought. Iran is already one of the world's more arid countries, with only the north of the country having adequate precipitation. The 2008 drought raised significant concerns within Iran and by the FAO; due to the risk that increasing drought may lead to desertification. In the event climate change increases the incidence and severity of drought in Iran, it is important to begin planning for adaptation by conserving water and using it in ways that meet the ecological and social needs for water.

Acknowledgements

We thank Steve Colombo for helpful comments on an earlier version of the manuscript.

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Received: 23.03.2014
Accepted: 30.05.2014