Impact of grazing on range plant community components under arid Mediterranean climate in northern Syria

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This research was conducted under the auspices of the C.T de Wit Graduate School for Production Ecology and Research Conservation (PE&RC).

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Thesis
submitted in fulfillment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. Dr M.J. Kropff,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Tuesday 3 December 2013
at 1.30 p.m. in the Aula.

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Abdoul Aziz Niane
Impact of grazing on range plant community components under arid Mediterranean climate in northern Syria
209 pages.

PhD thesis, Wageningen University, Wageningen, NL (2013)
With references, with summaries in English and Dutch

ISBN: 978-94-6173-414-3

Dedicated to

All my family,

My father, who did not live long

My mother and brothers and sisters who just managed without the luxuries of modern living

My wife and children who patiently bore the brunt of my work which provided very little time spent with them that is so essential for normal and happy living.

Acknowledgements

I am, forever, indebted to the International Center for Agriculture Research in the Dry Areas (ICARDA) for allowing me and for allocating the necessary time and resources to do this PhD thesis while maintaining my full employment benefits. The full support and continuous, but gentle monitoring progress of the ICARDA management, in particular Drs Maarten van Ginkel and Michael Baum, the Assistant Director General for Research and the Director of the Biodiversity and Integrated Gene Management Program, respectively made the completion of the thesis possible.

The continuous motivation, technical and moral support and scientific guidance of my thesis supervisor, Professor Paul C. Struik was decisive for the successful completion of this thesis. The administrative and technical assistance of Sjanie and Wampie, the Crop Systems Analysis (CSA) centre secretaries were exemplary. They were always there with a smile, whenever needed. Thanks to all the CSA professors and students. I benefitted directly and indirectly from all of them through one-to-one meetings or through presentations and colloquiums sessions. Special thanks go to my Paranymphs Mrs Marcia de Melo Carvalho and Mr Yu Yang.

Thanks to the Al-Badia Rangeland and Sheep Directorate (BRSD) of the Syrian Ministry of Agriculture and Agrarian Reform (MAAR) and its Integrated Range Rehabilitation Project (IRRP). Special thanks are due to the BRSD Aleppo province branch staff led by Mr. Badre Steif. The IRRP project manager Mr. Imad Kassah and its Aleppo branch team led by Mr. Nawaf El-Eibish and his deputy Mr. Khaled El-Aghab are among those to whom I feel obliged to mention. They provided all the necessary logistics, scientific guidance and access to the range rehabilitation sites for data collection. They also introduced me to the people living in and around the rangelands and facilitated my interaction with them to get a better insight into the rangeland issues.

I would also like to express my deepest gratitude to the ICARDA professionals in the Range, Forage, Biometrics, Soil laboratory, GISU (Geographic Information Systems) and CODIS (Communication, documentation and information system). To name a few: James Tiedemann, Asamoah Larbi, Mounir Louhaichi, Fahim Ghassali, Amin Khatib, Murari Singh, Khaled El-Shamaa, Layal Atassi, Fawaz Tulaymat, Wolfgang Goebel, Rolf Sommer, George Estefan, Seid Ahmed Kemal, Abdalla Bari, Ahmed Amri, Basima Barhom, Majed El Khatib, and Abdulrahman Hawa.

Special thanks to the technical and administrative staff of the ICARDA Seed Unit. In particular Drs Tony van Gastel and Zewdie Bishaw, the former and current Heads of Unit respectively under whose leadership and guidance this project was initiated and completed. The assistance of the technical staff, namely Mr. Talal Abdel

Karim, Mr. Hossein Battoh and Hyam El-Alawi in data collection, processing and entry of both the field and controlled environment experiments was crucial for the successful completion of the research activities.

Last, but not least, the twins of my soul my personal and extended family. The heaviest burden from this project was shouldered by them. Many holidays, vacations and parties were organized without me. To my dear wife Fatou and children Mohamed, Saed and Mbaye and to my short lived father and wonderful mother, brothers and half brothers, sisters and half-sisters, I would like to dedicate this work for which they have sacrificed more than me.

Abstract

Abdoul Aziz Niane (2013). Impact of grazing on range plant community components under arid Mediterranean climate in northern Syria; Doctorate thesis, Wageningen University, Wageningen, The Netherlands, 209 pp., with references, with English and Dutch summaries

Rangelands represent 70% of the semi-arid and arid Mediterranean land mass. It is a natural habitat for millions of people whose livelihood depends on animal husbandry. The revolutionary developments in the animal husbandry and veterinary medicines resulted in exponential increases in human and livestock population living on and from dry lands. To respond to population growth, urbanization and transportation means and expanded road networks, land reform and rural development policies forced nomads to adopt semi to fully sedentary lifestyles with disintegrated traditional community structures and organizational frameworks. Under these demographic changes coupled with national and international border crossing restrictions, there was an escalation in opportunistic cultivation, and excessive exploitation of the scarce and slowly renewable vegetation cover resulting in a steep decline in the primary production components of the rangeland ecosystems. In an attempt to stop and reverse the degradation process, large-scale re-vegetation programs based on transplanting and reseeding with perennial shrubs, resting and grazing management systems were devised and implemented. This study aimed to evaluate the impacts of the rehabilitation programs on the above-ground vegetation cover and soil seed bank replenishment in the Syrian rangelands. The underlying assumption of the rehabilitation program is that with a well-established perennial plant cover and proper grazing management, top soil is stabilized, soil moisture, nutrients and seed bank are replenished, organic matter is accumulated and microorganisms' activity is promoted resulting in greater abundance, species richness and diversity of annuals. To test the above hypothesis, field and controlled environment based studies were carried out with quantitative data collection and processing on plant species abundance, richness and diversity of above-ground vegetation and soil seed bank for fully protected rotationally and continuously grazed areas of 10 rangeland sites in northern Syria for three consecutive seasons.

In addition to the use of frequentist statistical approaches for species diversity estimation in the studies, the Bayesian method was explored. Moreover, the crucial issues of seed quality in re-vegetation were tackled through a study on seed viability and longevity in Salsola vermiculata L., which is a highly palatable, well adapted and widely used species in the arid Mediterranean rangeland rehabilitation programs.

The major findings are indicated below.

Above ground vegetation cover

The vegetation cover data analysis using ANOVA showed that overall plant density consistently declined from full protection to rotational and then continuous grazing in 9 out of the 10 sites studied, whereas the trends of change in species richness and diversity were not consistent.

Pair-wise comparison showed that plant density, species richness and diversity were lowest for the overall plant population under rotational grazing in which plant density of perennial grasses was highest. This suggests that rotational grazing has reshaped the composition of the plant communities under the study areas by promoting the perennial grasses that are more arid rangeland adapted and ecosystem significant. Higher plant density under rotational grazing and similarity in species diversity under the three grazing treatments for perennial grasses imply that a longer period of rehabilitation and/or probably incorporating inter-seasonal rotational grazing and variation in herbivore types into the current intra-seasonal rotational grazing system will be required to cross the line of no return in plant community composition optimization through the prevalent arid Mediterranean rangelands rehabilitation programs.

Soil seed bank assessment

The soil seed bank data analysis using ANOVA showed no significant differences in the overall physical and germinable soil seed bank size and diversity along the grazing gradient. However, there was a significant grazing-by-site interaction for both and a significant grazing-by-year interaction for germinable seed bank size showing that the change in seed bank size is moderated by physical and environmental characteristics and human-induced disturbances. Continuous grazing treatments for some sites were located near agglomerations of people and animals, main roads and water points. Under such conditions the more disturbance-adapted ephemerons and non-palatable plants with limited constraints for seed setting dominated and this resulted in a larger soil seed bank under continuous compared to rotational and full protection grazing treatments. For the more human-induced disturbance distanced sites, the soil seed bank was at larger or similar under full and/or rotational compared to continuous grazing.

Results from pair-wise comparisons showed a simultaneous decline and surge in physical and germinable soil seed bank size of annuals and those of perennials under the grazing treatments over sites. This suggests relative differences in root competition and gap exploitation characteristics among plant functional groups; these differences could be considered indicative to rangeland status and a guide to vary herbivores in order to maintain optimum plant species diversity in the target rangelands.

Soil seed banks with no seeds of perennial grasses generated 208 seedlings m^{-2} of germinable soil seed bank under continuous grazing. This is probably due to seed setting failure resulting from overgrazing compensated by vegetative reproduction. The widely used phanerophytes in the rangeland rehabilitation program had a physical soil seed bank of 59.7 to 119 seed m^{-2} and a zero germinable one. This shows high complementarity between physical and germinable seed testing methods for rangeland monitoring.

Similarity indices

High Morisita-Horn and Sørensen similarities were recorded between the quadrat and point intercept measurements of the above ground vegetation and with each of physical and germinable soil seed banks. However, the similarity indices of the above ground vegetation measurements were higher with the germinable soil seed bank than with the physical soil seed bank. This suggests that the germinable soil seed bank is more suitable for monitoring arid Mediterranean rangeland than the physical soil seed bank.

Correlation coefficients

Based on the coefficients of determination (CDs), the variation in plant density and seed bank size accounted for a significant portion of the variations in spcies richness but not of the diversity indices. However, plant density and species diversity consistently and significantly declined during the season with the lowest mean annual precipitation showing the crucial role of precipitation in the dynamics of the yet active soil seed banks of the study areas. The CDs for the germinable soil seed bank size tested under optimum soil moisture with species richness were also significant throughout the grazing treatments reflecting the dependence of seed bank dynamics on soil moisture.

For the physical soil seed bank (PSSB), CDs of its size with species richness were only significant under rotational grazing implying positive impacts of grazing management on soil seed bank replenishment. Morover, the CDs of PSSB richness with the diversity indices were only significant for Singletons but not for Shannon and Simpson. This is attributable to the fact that the Singleton index is more sensitive to rare species than Shannon and Simpson. The non-significant correlations between plant density and species diversity reflect a need to incorporate inter-seasonal rotational grazing and herbivore variation to the current intra-seasonal rotational grazing for greater plant community integrity.

Phytogeographic analysis

Using two above and two underground vegetation data collection methods, a total of 137 species, including 102 annuals and 35 perennials from 36 families of 11 chorotypes, were recorded. The number of species recorded were 56, 66, 68 and 98 from physical seed extraction, point intercept, quadrat and grow out test, respectively. These results showed the superiority of the growing out test over the three other methods. With its easiness and relative flexibility of application in terms of time and space, the grow out test seems to be the best method for arid Mediterranean rangelands monitoring and assessment of rehabilitation impacts in which the frequency of good rainy season is one out of four years.

Conclusions

- The rotational grazing component of the rangeland rehabilitation program resulted in a change in plant community composition shown by an increase in low proportional abundance perennial grasses with greater arid Mediterranean rangeland adaptation.
- Continuous grazing reduced plant density but not richness and diversity, indicating that maximum diversity is not a sign of rangeland health and integrity. This also suggests that inter-seasonal rotational grazing and herbivore variation could probably improve the shaping effects of grazing on the arid rangeland rehabilitation programs.
- Capturing more species and higher similarity indices with the above ground measurements, the simple and flexible, germinable soil seed bank test seems to be

a good monitoring and evaluation method for arid Mediterranean rangelands. However, results from the tedious and less accurate physical seed extraction method could be crucial to capture the species with long seed dormancy.

- Larger Bayesian estimates of diversity, smaller standard errors, lower p-values and more significance of differences in diversity between grazing treatments compared to the frequentist approaches were observed, thus indicating clear merits for the approach in estimating diversity.
- The seed longevity study showed that under relatively higher seed moisture content, longevity increased suggesting that desiccation susceptibility is probably the cause of short seed longevity of *Salsola vermiculata* L. Moreover, drying and packaging alone increased longevity, thus providing a simple, cost-effective and environmentally friendly method for rangeland rehabilitation programs.

Keywords: Rotational grazing, full protection, continuous grazing species richness, species diversity, soil seed bank, Bayesian methods, *Salsola vermiculata*, seed longevity, rangeland management, Syria.

Table of contents

Chapter 1

General introduction

Chapter 1: General introduction

In this chapter, the general background of the research work and its relevance are discussed. The introduction is based on a comprehensive literature review, extensive field visits and direct communication and interaction with scientists and professionals in the field of research and management of arid Mediterranean rangeland in general and in particular in Syria. In 1999, the Mediterranean and Middle East Research and Studies Group of the Lyon-2 University in France developed a land use and vegetation cover map for the arid margins of Syria in cooperation with the International Center for Agriculture Research in the Dry Areas (ICARDA) using satellite imagery techniques. One of the short comings of the study listed was that it was not possible to differentiate between crop stands of different plant species such as barley, wheat and lentil. Nevertheless, the study generated a valuable satellite imagery of the Aleppo, Hama and Homs arid Mediterranean rangelands at macro level with basic information on topography, soil characteristics and vegetation cover types (Jaubert et al, 1999). This study aimed at going one step further to look into the vegetation cover at micro level under the study areas six years later.

1. The rangelands

1.1. Definitions

Rangelands are areas dominated by self-propagating vegetation comprised predominantly of grasses, grass-likes, forbs, shrubs, and dispersed trees (Gyde, 2011; SRM, 1989). They are extensive ecosystems occupied by native herbaceous or shrubby vegetation grazed by domestic or wild herbivores. Temperate and tropical forests that are used for grazing as well as timber production can also be considered rangelands. Rangelands cover a wide range of vegetation types such as tall grass prairies, steppes (short grass prairies), desert shrub lands, shrub woodlands, savannas, chaparrals, and tundra (Ludwig, 2008; Wayne & Stubbendieck, 1986). Several variants of the above definition and elaborations exist in literature, with self-propagation, native vegetation, herbivory and extensive management, as common denominators (Service, 2010; Paruelo & Oesterheld, 2006; SRM, 1995). Rangelands are ecosystems sustaining people and livestock living in and from them, natural flora and fauna adapted to them, soil, topography, microbiology, hydrology and climatology characterizing them. Rangelands are distinguished from pastureland which is dominated by domesticated vegetation with higher stocking rate and agricultural intensification management i.e. cultivation, seeding, irrigation, fertilizer application and harvesting (Valentine, 1980). Lund (2007) strongly argued that, due to variability and overlapping in the criteria of classification, a comprehensive revision of rangeland definitions is required. He listed land cover, land use, ecology and management as the criteria on which the existing definitions were based. He concluded that forest land used for grazing is considered rangeland ignoring the fact that it is also used for timber production, cultivation for pasture and crop production, etc. He suggested defining rangelands as: “Any dry land at least 0.5 ha in size and 20 m in width having at least 10 percent vegetation cover at least 2 months of the year and less than 10 percent tree (any woody perennial at least 5 m tall) cover and that is not used for growing crops”. This definition seems to be more relevant to the arid and semi-arid Mediterranean rangelands in which this study was carried out.

1.2. Rangeland classification

The plant community succession concept which refers to the sequential replacement of species in a community through immigration of new species into it and due to local extinction of old ones, resulting from disturbance, has long been the conventional concept for rangeland classification and assessment. The concept, quoted in SRM (1995), was introduced by Sampson (1920). There are two categories of plant communities; namely terrestrial and aquatic, covering the entire globe. The terrestrial communities are subdivided into seven categories or biomes containing many communities of a similar nature, whose formation and continuation is largely controlled by climate, soil and topography. The terrestrial biomes are tundra, grassland, desert, taiga, temperate forest and tropical forest. The aquatic category consists of marine and freshwater biomes (Chape et al., 2003). The natural self-propagating vegetation areas grazed by wild and domestic herbivores among each of the terrestrial communities are termed rangelands, thus the biome classification criteria are readily applicable to rangelands (Pratt and Gwynne, 1977).

Rangelands occur around the globe in areas too dry or with soils and topography unsuitable for broad-acre farming but fertile and wet enough for pastoralism. Because pastoralism may intensively utilize water and vegetation some rangeland areas can become damaged (Ludwig et al., 2008). This statement is in line with the non-equilibrium concept in rangelands linking potential of degradation to water availability (Henrik et al., 2012; Behnke and Abel, 1996). Using the plant community succession method, Sankary (1988) developed a map of plant communities for the arid and semi-arid areas of Syria. The map consists of 12 plant communities as quoted in ACSAD (2004). Using bioclimatic factors, Le Houerou (1981) classified the Mediterranean vegetation based on mean annual precipitation into arid, semi-arid and humid, each of which was then subdivided based on minimum temperature into four categories, namely warm, mild, cool, cold and very cold winter.

1.3. Rangelands significance

The term rangelands, also defined as land in which wild and domesticated livestock wander for food (Catharinus & Thalen, 1979), is temporally linked to the existence of herbivores on earth. In terms of space, rangelands extend over the five continents, representing 55% (Fig. 1) of the world's total area of lands and 75% (Fig. 2) of the Mediterranean basin (Louhaichi, 2011; Gintzburger, 2005; Le Houerou, 1981).

In Syria, the rangelands cover 10.2 million ha representing 55% of the total area (ACSAD, 2004) and 97.4% of the non-agricultural land (Sankary, 1977). Rangelands are major sources of free feed for domesticated animals, natural habitat for wildlife, amenities and tourism all over the world. The estimated percentage of rangeland contributions to ruminant feed supply is 60-90% in the West Asia and North Africa (WANA) region. In Syria, Mourad (2000) and ACSAD (2004) estimated it at 60% and 40%, respectively.

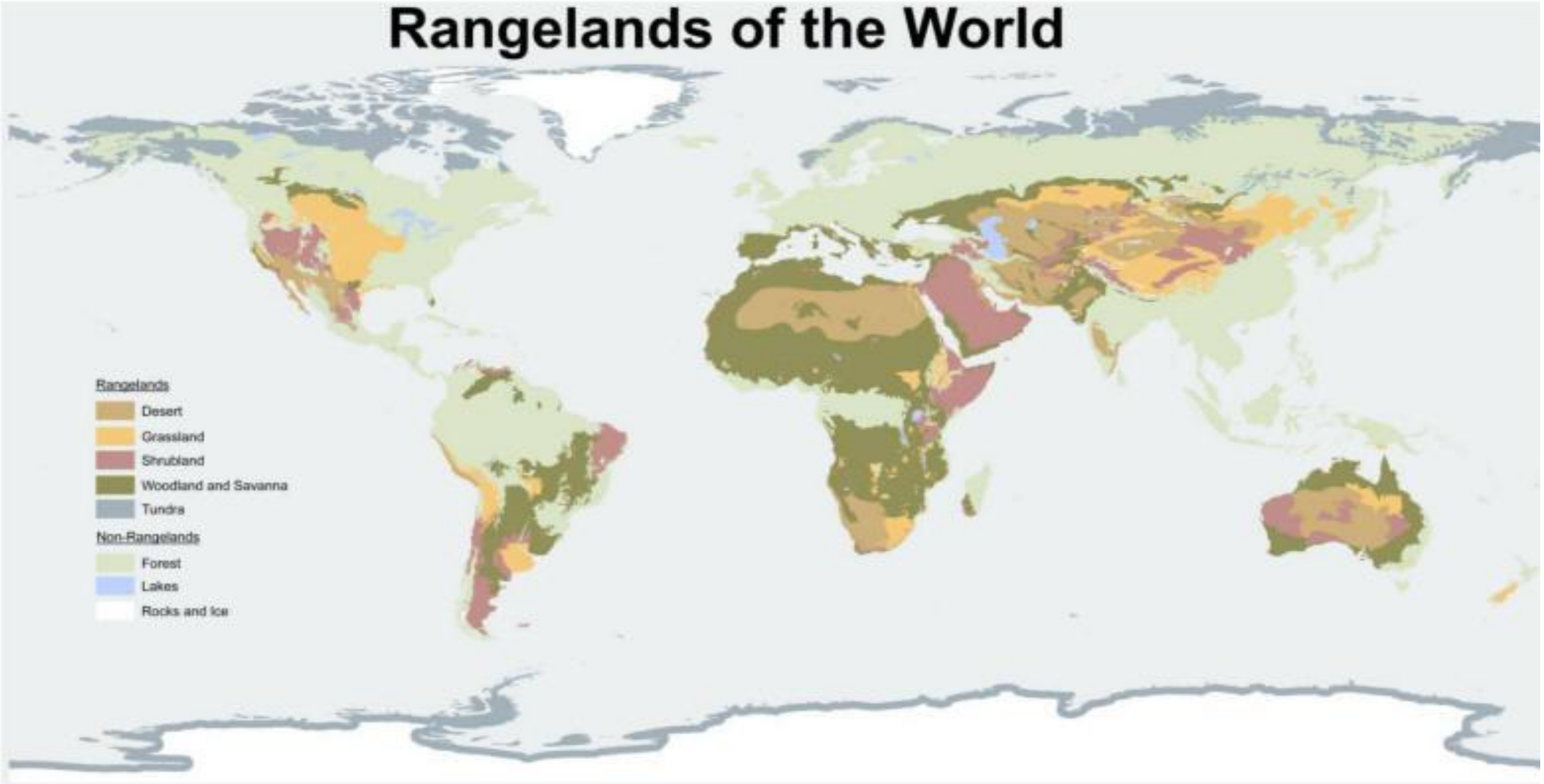

Figure 1: World’s Rangelands Map: http://www.cnr.uidaho.edu/what-is-range/rangelands_map.htm. This map of rangelands of the world is a joint project of the Information & Education (I&E) and Remote Sensing & GIS committees of the Society for Range Management (SRM). The project was conducted by two professors from the Rangeland Ecology and Management Department at the University of Idaho, Karen Launchbaugh and Eva Strand, with input from the SRM I&E committee.

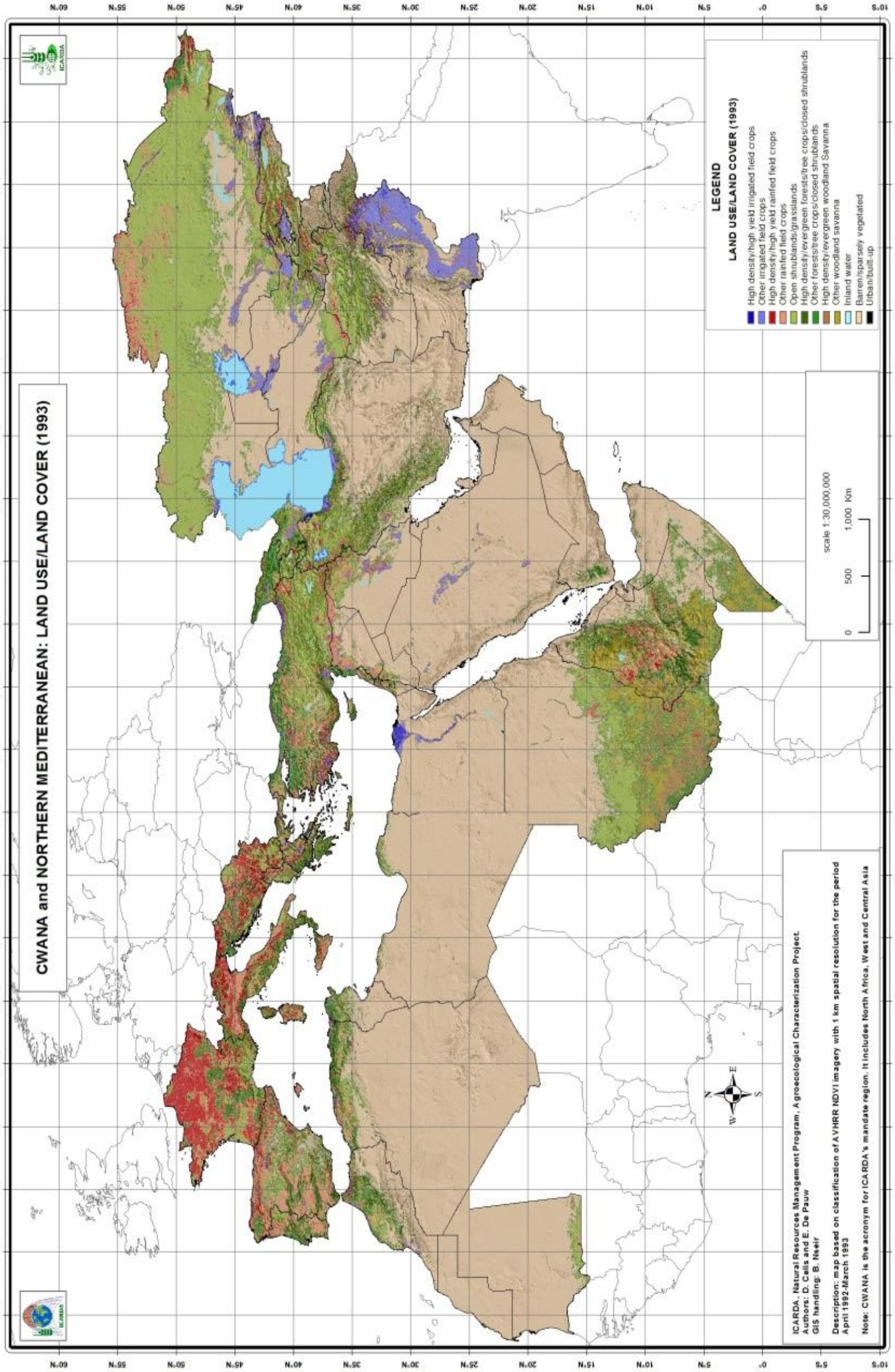

Figure 2: Land use and cover map for Northern Mediterranean Region of Central and West Asia and North Africa region. Provided by the ICARDA GIS unit

1.4. Condition and monitoring of rangelands

Rangeland condition refers to the 'state of health' of an area assessed by measuring attributes and indicators of its current functional state relative to an expected norm which is usually the current or potential climax of the plant community. An indicator is a simple surrogate or index for a difficult-to-measure attribute (Ludwig et al., 2008).

According to the Task Group on Unity in Concepts and Terminology (UCT) commissioned by the Society for Range Management (SRM), range condition score or classification does not provide rangeland managers with reliable information on biodiversity, erosion potential, nutrient cycling, value for wildlife species, or productivity across all rangelands (SRM, 1995). The UCT Task Group stated that range condition score or classification is built on an assumed linear and positive relationship between plant community succession and grazing pressure. In other words, range management is analogous to grazing management. The linearity assumption has been largely contested based on the fact that it does not recognize site potential, differences in soil, topography, and climate, which are the major determinants of the kind and amount of vegetation which can be produced on a given piece of land, and also the "natural" levels of soil erosion which can be expected. Failure to recognize these site differences results in classifying some land in "poor" condition when it does not have the potential to be any better. This premise is well established in the range profession and is recognized in most (but not all) current rangeland condition assessments (Dyksterhuis, 1949; Laycock, 1947). The recommendations made by the Task Group and adopted by the SRM were:

1) Evaluations of rangelands should be made on the basis of the same land unit classification, ecological site;

2) Plant communities likely to occur on a site should be evaluated for protection of that site against accelerated erosion (Site Conservation Rating, [SCR]); and

3) Selection of a Desired Plant Community (DPC) for an ecological site should be made considering both SCR and management objectives for that site (SRM, 1995).

The UCT Task Group assessment is one of the most comprehensive syntheses of range monitoring principles and applications I came across in this literature review. The recommendations made represent valuable guidelines based on which the arid Mediterranean rangeland rehabilitation programs can benefit.

1.5. Rangeland management

Compared to other basic sciences and disciplines, range management as known and practiced today, started at the beginning of the 20th century. Holechek (1981) reported that range management is perhaps the only science that is entirely American in origin and development. According to him, scientifically based range management started in the mid 1890s, with the first range experiments concerning correct stocking rate, range pitting and range seeding carried out by H.L. Bentley and the first grazing system experiments in Oregon by Arthur Sampson between 1910 and 1915. Prior to these research activities, Holechek (1981) reported that "National Forest ranges began to improve again after World War I because scientific range management practices and controlled grazing were once again implemented. The discipline of range management flowered and developed in the 1920s during which 15 colleges were active in teaching and awarding degrees on range management".

As self-propagating vegetation with animal grazing as primary land use, rangelands cover a wide range of natural habitats and ecosystems across all the biomes of the earth. As such, rangeland management can be considered applied ecology dealing with all the action and interactions of range ecosystems components and functions. It is one of the major natural resources management disciplines dealing with natural soil, topography, flora, fauna, and climate. It is a fully-fledged, integrated and stand-alone scientific discipline aimed at maximizing outputs from the extensive natural pastures through manipulation of range ecosystem components and functions, namely plant community succession, energy flow and nutrient cycling. Range ecosystems vary in time and in space, thus range management concepts and approaches need to be adjusted accordingly. Sustaining productivity and health status of rangelands resources at good status and rehabilitation of degraded rangelands would require different approaches. The rangeland management techniques and configurations need to be adapted to rangeland types to be managed. Significant differences in techniques and configuration would be required to manage rangelands with significant differences in topography, soil type, water regimes, climatic conditions, vegetation type, fauna and health status. Anonymous (2009) defined grazing management as the manipulation of animal grazing to achieve desired results based on animal, plant, land, or economic responses, but the continuing immediate goal is to supply the quantity and quality of forage needed by the grazing animal for it to achieve the production function intended. Grazing management is important because this is where theory is put into practice. For Sampson (1923) grazing management involves the regulation of this consumptive process by humans, primarily through the manipulation of livestock, to meet specific, predetermined production goals. For Stoddart & Smith (1975), *Range Management* is "The science and art of optimizing the returns from rangelands in those combinations most desired by and suitable to society through the manipulation of range ecosystems". According to Heady & Child (1994), "Range management is a discipline and an art that skillfully applies an organized body of knowledge accumulated by range science and practical experience for two purposes: (1) protection, improvement, and continued welfare of the basic resources, which in many situations include soils, vegetation, endangered plants and animals, wilderness, water, and historical sites; and (2) optimum production of goods and services in combinations needed by society”. He added that “Management of rangeland requires selection of alternative techniques for optimum production of goods and services with no resource damage... While emphasis is often placed on effects and management of domestic animals, the overriding goal is rangeland resource rehabilitation, protection, and management for multiple objectives including biological diversity, preservation, and sustainable development for people”. SRM (1995) concluded that “sustainability” is the fundamental goal of rangeland management and sustainable management and rangelands depend primarily on conservation of the soil. Management should not result in irreversible reductions of soil productivity if that can be avoided. The primary cause of irreversible loss of soil productivity on most rangelands is erosion by wind and water.

2. Mediterranean rangelands

2.1. Significance and classification

Up to 70% of the total land areas in the Mediterranean basin are rangelands in which bioclimatic conditions of long, dry and hot summers with short, rainy and cold winters dominate. In terms of plant physiognomy, the Mediterranean pasture is classified into productive forests (50%), maquis and garrigue (35%), dry grassland (10%), meadows or depressions (2%) and halophytic steppes (2%) (Le Houerou, 1981). The Mediterranean rangelands are rich in vegetation, but due to the length of the dry summer period, suitability for grazing during winter, high livestock and human population, are fragile and prone to degradation (Gallacher & Hill, 2006; Sidahmed, 1996; Le Houerou, 1981). Due to the above-mentioned factors, rangeland degradation, defined as a process that leads to an irreversible reduction in the capability of an ecological site to produce vegetation, is considered a reality in the Mediterranean basin (Louhaichi, 2011). Rangeland degradation is one of the most important factors of desertification in the south of the Mediterranean basin (Le Houerou, 1981).

2.2. Status of Mediterranean rangelands

After World War II, the number of sovereign countries in the Southern Mediterranean basin steadily increased; tribal boundaries within and between countries were phased out and were replaced by strictly controlled national and international border lines. The newly established states adopted revolutionary agrarian reforms and land reclamation policies and regulations, cropping areas were extended, veterinarian services improved, road networks constructed, urbanization expanded and water points established. These changes resulted in an exponential increase in the animal population and in a rapid change in the lifestyles of the rangeland inhabitants from nomadic pastoralists to sedentary residents with advanced communication, mass livestock transportation and mechanized opportunistic cultivation facilities putting great pressure on the fragile rangeland ecosystems with limited self-regeneration capabilities due to long and dry summer seasons, vegetation exposure during winter due to lack of snow, alternative feed deficiency and maintaining large flocks of animals for social prestige and as a symbol of power (Sanlaville, 2003; Geerken et al, 1998; Sidahmed, 1996). Le Houerou (1981) summarized the history of degradation in the Mediterranean basin: "Mediterranean vegetation has been in a general state of regression since the Neolithic. There have been periods of intense degradation during periods of political calm, economic prosperity and demographic expansion, alternating with periods of remission during the course of troubled periods following war, famines and epidemics which have been characterized by economic and demographic regression and sometimes by return of the sedentary population to a nomadic life. This degradation is essentially the result of human activity: Climate does no more than provide favorable, though constant, conditions".

2.3. Management of Mediterranean rangelands

In the non-European Mediterranean arid and semi-arid zones, systematic use of fodder trees and shrub plantation started between World War I and II, then expanded and diversified between 1950 and 1970 in Tunisia and beyond. However, for the herbaceous fodder species with far less adaptation to arid lands, there have been no activities or progress worth mentioning (Le Houerou, 1981). The range ecologists sounded the alarm, devised strategies and developed technologies and techniques to stop and reverse the rangeland degradation process. The techniques included resting, access control, transplanting and direct seeding to counter the effects of excessive use of range land resources and to restore its ecosystem integrity. These activities have been going on for decades in the arid Mediterranean rangelands of many countries in the West Asia and North Africa Region (WANA) (Louhaichi, 2011). The range ecosystem recovery and expansion resulting from the above activities seem to be far below the most conservative expectations. Moreover, hard data on the effects of the long- and short-term range rehabilitation activities on the restoration of its self-regeneration system are scarce. In particular, information on the active soil seed bank size, seed quality and botanical diversity seems to be in serious short supply.

3. Syrian rangelands

3.1. Classification and significance

The Syrian rangelands are typically Mediterranean in nature and in status. They are characterized by long, hot and dry summers with short, cool and damp winters. Out of the Syrian total land area of 18.5 million hectares (ha), 10.2 (55%) are rangelands. The area sustains about 600,000 Bedouins (Transhumant) at a density of 0.5 inhabitants per km^2. The main source of livelihood for 60% of them is livestock which depends on the extensive rangelands resources as the major source of feed (Fig. 3).

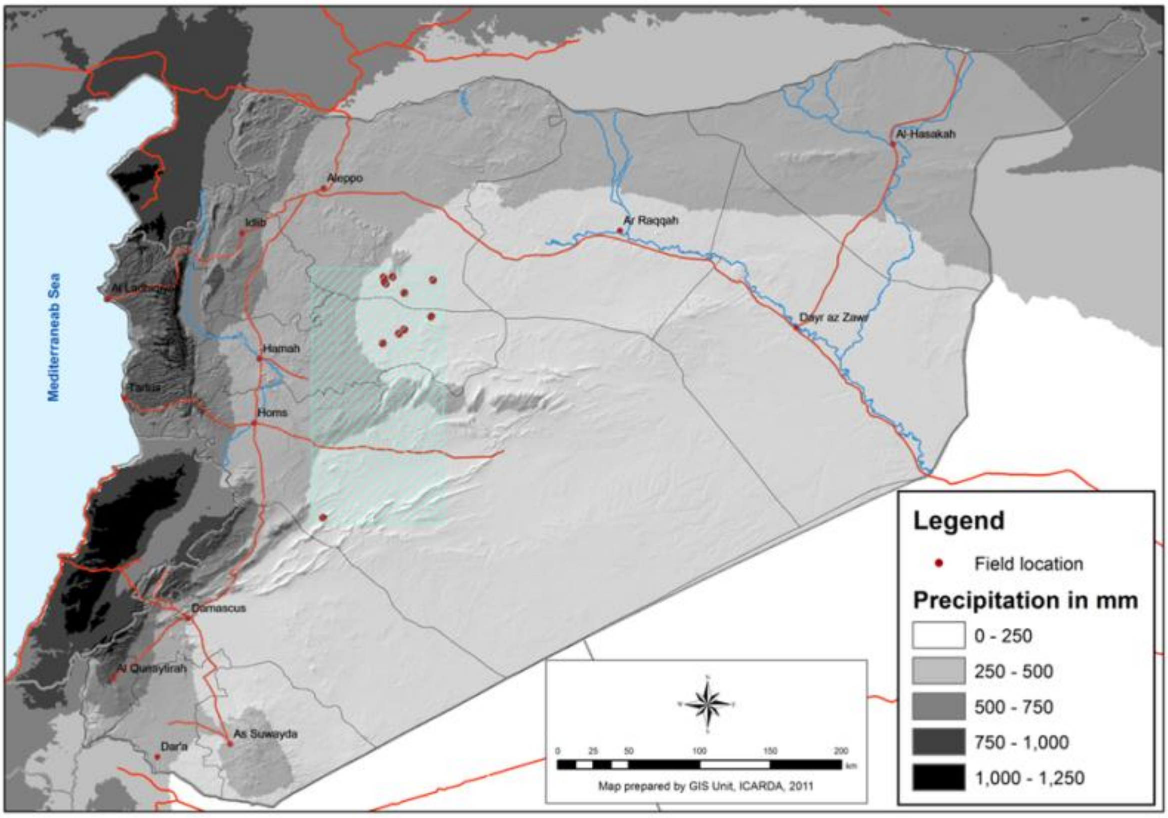

Figure 3: A precipitation based map of Syria with its rangelands under 0-250 mm/year precipitation, provided by the ICARDA GIS Unit.

3.2. Syrian rangeland status

Due to the natural, demographical, cultural and historical reasons mentioned earlier, the Mediterranean arid rangelands are, generally, at advanced levels of degradation. The Syrian rangelands are no exception to this. The root causes for rangeland degradation in Syria are mainly manmade, in particular overgrazing, opportunistic cultivation, fire and timber collection (Musallam, 2003). To stop and possibly reverse the rangelands degradation process, the Syrian government banned opportunistic cultivation of cereals in the rangelands by Decree No. 11 issued in 1995 and issued many more (Table 1).

In the 2007 statistical abstracts published by the Syrian Ministry of Agriculture and Agrarian reform, the sheep population in Syria has been fluctuating between 15 and 20 million heads during the last decade (Anon., 2008).

Table 1: Major rangeland management related laws and decrees in Syria.

Law	Date	Implications	Consequences
Law of tribes abandoned	1958	Tribal leadership authorities compromised	Less control over tribal boundary
General Union of Peasants (GUP) established	1974	Subsidized feed, rural development and veterinary services provision	Animal population growth
GUP decision No. 127 for open access to grazing land	1977	Common land tenure system	Less incentive for investment
Decree No. 11 banning cultivation areas (<200 mm)	1995	Less opportunistic cultivation	Natural flora protected

The results of a study carried out from 2001 to 2004, covering 3.5 million hectares, showed that the carrying capacity of the area studied is 1.33 kg of dry matter ha^{-1} day^{-1} for 180 days, which is the maximum period of grazing $year^{-1}$ in the Syrian steppes (ACSAD, 2004). With the estimated stocking rate of 1.15 kg dry matter $head^{-1}$ ha^{-1} day^{-1} proposed by ACSAD in 1995 cited in (ACSAD, 2004), the 10.2 million ha, can sustain about half of the 20 million heads of the Syrian sheep population. Talking about the consequences of degradation of natural resources, Le Houerou (1981) stated that the productivity of highly degraded maquis and garrigues have a net primary production of 600 to 1200 kg ha^{-1} yr^{-1} which is about three times the reported carrying capacities reported in the ACSAD study. He also estimated the average annual stocking rates in the Mediterranean zone in 1981 at 1.7 sheep-equivalents ha^{-1} $year^{-1}$ which is equivalent to food consumption in the order of 1500 kg ha^{-1} yr^{-1} of dry matter.

A case study report prepared under the FAO project (GCP/SYR/009/ITA) entitled “Rangeland Rehabilitation and Establishment of a Wildlife Resource in Al Badia Region” estimated the total annual dry matter yield in Al Badia at 2,100,000 tons (FAO, 2006). Therefore, it was concluded that the number of sheep units that the range can support is approximately 5.2 million sheep units and the correct stocking level is therefore some three times lower than the actual stocking level. Based on the above, stocking rate reduction can be considered a first option to adopt in the Syrian rangeland rehabilitation. However, the current rangeland rehabilitation programs are more oriented into revegetation and grazing management, which may explain the debatable significance and sustainability of their outcome.

3.3. Rangelands rehabilitation in Syria

In Syria and Mesopotamia, an exclusive system of right to access to range resources known as ‘hema’ or tribal boundary was well-established and recognized until the mid-20th century (ACSAD, 2004; Jaubert, 1999; Al-Issa, 1998; Sankary, 1977). The relative advantage of hema over the state ownership land tenure system is that it provides the tribes with more incentives to invest and protect the land resources from overgrazing and excessive utilization of the range resources. Seasonal migration towards and from the steppes dictated by climatic variations within and between seasons is also claimed to have been practiced for centuries in Syria and Mesopotamia to rationalize the use of range resources. (ACSAD (2004), Sanlaville (2003), Catharinus & Thalen (1979, Sankary (1977) referred to the system as traditional pastoral practices, where the flocks visited the pastures twice a year, in spring and in autumn, taking into account the fragility of the steppe environment, and giving it time to recover between grazing. The flocks would leave the steppe during the latent season, to go and crop the stubble in the cultivated areas (in summer) or to retreat into the desert (in winter). Since the end of the 19th century, however, and at an ever-quickening pace, pressure on the steppe has increased.

Like most countries with arid rangelands in the Mediterranean basin, systematic application of modern techniques of range management and rehabilitation started in Syria after World War II. The rehabilitation program focused on some biophysical components; namely shrub plantation, rotational grazing and resting with less or no consideration of the policies and socio-economic issues, which may explain the limited achievements on the targeted goals of stopping and reversing the rangeland degradation process.

The natural revegetation program in Syria comprises both policy and three biophysical approaches. In the area of policy, four major decrees have been issued (Table 1) during the last six decades consisting of three main components:

(1) The establishment and operation of seven pasture seed multiplication centers with a production capacity of 100 metric tons of seed per year for production of shrub seedlings;

(2) The establishment and operation of 13 pasture nurseries aimed at the production of seedling from locally adapted plant species for revegetation of degraded rangeland areas with an annual production of about 10 million seedlings; and

(3) The establishment and management of 28 range reserves covering a total of 125,000 ha aimed at revegetation, production of seed to expand the program, soil and wildlife protection, desertification control, alternative feed supply and creation of employment (Mourad, 2000).

The seed production/collection, direct seeding and seedling production and transplanting in the range reserves are combined with a rotational grazing of full protection during the 2-3 years of establishment followed by a controlled access grazing management system in which the reserves are open for 2 months in autumn and early spring at a nominal fee of 0.20 US$ head^{-1}. This grazing management system aims at protecting the transplanted seedlings during the early establishment stages and promoting aerial and soil seed bank replenishment during the later stages of the range reserve improvement.

Most rangeland rehabilitation programs in the Arid Mediterranean basin including Syria and other southern Mediterranean countries are based on the shrub plantation and associated rotational grazing systems described above. It is clear that soil and aerial seed banks from the wild or mother plant nurseries play a pivotal role in the system. The seed collection/production depends on aerial seed banks, whereas the rotational grazing based programs focus on the natural soil seed banks, residual vegetation and associated propagules. In both programs, seed banks play a pivotal role.

4. Grazing management

4.1. Grazing management definition

Grazing animals may be kept in the paddocks continuously or intermittently. The first method is known as continuous whereas the latter is referred to as rotational. Rotational grazing is about alternating periods of grazing and resting for two or more paddocks in a grazing management unit throughout the grazing season. Continuous grazing is a method of grazing livestock on a specific unit of land where animals have unrestricted and uninterrupted access throughout the grazing season. The aim of rotational grazing is to maximize seed setting and raining to promote regeneration by removing grazing animals from the paddocks at the critical stages of shrub establishment and seed setting (Sollenberger, 2010).

4.2. Rotational grazing for range rehabilitation in Syria

In the Syrian arid Mediterranean rangelands, rotational grazing has been adopted as part of the rangeland rehabilitation package consisting of the establishment of range reserves at high potential range sites, the introduction of rangeland adapted shrubs through transplanting combined with 2 to 3 years of continuous resting to ensure shrub establishment followed by the application of rotational grazing with appropriate stocking rates. In the Syrian arid Mediterranean rangelands, reserves are closed for 2 to 3 years following shrub transplanting, then opened for grazing in the autumn and in the spring after full seed setting for shrubs and annuals respectively.

5. Soil seed bank

5.1. Soil seed bank definition and classification

A natural seed bank is the total stock of seed produced by a plant community. Two kinds of seed bank exist: soil and aerial. The soil seed bank is defined as the mature viable seed stock in the soil surface, or buried in the soil or litter, at a given moment and place (Walck et al., 2005; Martins, 2007). It is simply the reservoir of seeds and fruits on or in the soil (Fang & Cai, 2011; Zhou & Du, 2010; McLaughlin & Bowers, 2007). The aerial or canopy seed bank refers to the portion of seed retained by the plant or collected and stored for propagation purposes (Fenner, 2008; Gulden & Shirtliffe, 2009). Natural soil seed banks are classified according to their longevity as long-term persistent, short-term persistent or transient. Soil seed banks with seed longevity above 5, between 1 and 4 and less than 1 year are classified as long, short-term and transient, respectively (Verhoustraeten & Baur, 2011; Poschlod & Setchfield, 2003; Harrington, 1960).

5.2. Soil seed bank size and quality

Most rangeland plants rely on seed for regeneration**.** Soil seed banks are potentially major propagule sources that can have a significant input to vegetation community structures (Feng-Rui Li, 2008; Warr et al., 1993). On one hand, vegetation distribution is related to the initial framework created by the patterns of seed arrival (Bao & Wu, 2011). Thus, aerial and soil seed banks are the basic sources of vegetation replenishment. Ma et al. (2010) stated “Our results suggest that the establishment of new species in severely disturbed areas is more dependent on the seed bank. By contrast, the restoration in less-disturbed and mature meadows does not rely on seed banks, and the establishments of the vegetation in these communities are more likely to rely on seed dispersal from the standing vegetation and on species with vegetative reproduction”. McLaughlin & Bowers (2007) concluded that “An understanding of seed persistence in the soil is important to vegetation management and weed control, but experimental collection of seed bank data is tedious and expensive. The seed banks in most submontane soils are potentially important seed reservoirs, particularly where extensive severe disturbance of the vegetation prevents fresh seed dispersal. Information on buried germinable seed populations can be of practical value because of their influence on the nature and rate of plant succession that follows from the perturbation of established vegetation whether by long-term climatic change or by direct human interference". The availability of seeds in the soil seed bank is therefore generally assumed to be important for the regeneration of degraded natural habitats (Li et al., 2011; Maranon, 1998; Leck, 1989). A study on achene aerial seed bank dynamics concluded that seasonal aerial seed banks are effective within-season, risk-reducing traits in rural Mediterranean habitats characteristic of the study species (Bastida et al., 2010).

The poor soil, dry and hot climatic conditions of the arid Mediterranean rangelands combined with a lack of improved range plant genotypes with even seed setting and maturity, have a negative impact on the quantity and quality of seed available for use in the rehabilitation programs. Von Holdt (2000) reported extensive research on genotype and seed quality improvement and crop management practices carried out in South Africa on old man saltbush (*Atriplex nummularia*). The research resulted in the first improved variety of saltbush with a comprehensive seed technology and crop management packages. The research activities resulted in identification of the major seed quality constraints and generated appropriate techniques to address them. The seed quality constraints were related to propagation, picking, processing (de-husking and pelleting), storage, soil preparation and timing of planting. The appropriate techniques developed and tested were an improved saltbush genotype with homogenous seed setting and maturity, highly specialized picking, processing, and storage techniques which resulted in better germination percentage and field establishment due to low concentration of germination inhibitors and better seedbed preparation and timing of sowing.

6. Outline of the thesis

The objectives of the thesis are:

1. To study the impacts of rotational grazing on soil seed bank replenishment and vegetation cover composition, abundance and diversity; and
2. To investigate the seed quality and longevity promotion methods on *Salsola vermiculata* L. The high palatability of *Salsola* makes it one of the most threatened species and a major component of the Syrian and most arid

Mediterranean rangeland rehabilitation programs (Ouled Belgacem & Louhaichi, 2013).

3. To explore the use a Bayesian approach to estimate species diversity indices and compare it with the frequentist approach.

6.1. Hypothesis and research questions

During the last few decades, rangelands in the WANA region have degraded at an alarming rate. Overgrazing, opportunistic cultivation, excessive use of the scarce plant resources for firewood are the major causes stated. As reported by Holtz (2003), the United Nations Convention to Combat Desertification defined land degradation as reduction or loss, in arid, semi-arid and dry sub-humid areas of the biological or economic productivity. The referred degradation results from land uses or from a process or combination of processes arising from human activities and habitation patterns, such as: (i) Soil erosion caused by wind and/or water; (ii) Deterioration of the physical, chemical and biological or economic properties of soil; and (iii) Long-term loss of natural vegetation leading to a steep decline in native botanical diversity, plant density, top soil, organic matter, microorganism activities (David et al., 2012) and natural seed banks (Angassa & Oba, 2010). The key to stopping and reversing this rangeland degradation is widely believed to lie in revegetation and rotational grazing. Zobisch, (1993) reported that 40 percent green cover seems to be the critical level below which soil loss becomes serious. This level of green cover is reported in arid Mediterranean open grazed rangeland depressions under which highest level of soil moisture is accumulated (Louhaichi et al., 2012). For advanced degradation levels associated with severe soil erosion, however, direct and/or indirect reseeding is believed necessary to initiate and foster ecosystems restoration processes. Tessema et al. (2012) reported that restoration of grass and woody species from the soil seed banks in the heavily grazed areas could not be successful in semi-arid savannas of Ethiopia. Large areas of degraded rangelands in WANA, where Syria is located, fall within this category. Success and sustainability of rehabilitation for severely-degraded rangelands is widely believed to depend on how effectively rehabilitation methods and efforts replenish remnant top-soils and resources such as soil and aerial seed-bank size, quality, botanical diversity and abundance. Shannon and Simpson diversity indices and frequentist-based statistics are commonly used in plant population dynamics studies. In this study an attempt is made to explore the Bayesian approach for diversity estimation as compared to the frequentist based statistics.

- ➢ *Research question (1): What are the impacts of grazing management practices on vegetation cover abundance, composition and diversity under Syrian arid rangeland conditions?*

- ➢ *Research Question (2): What are the impacts of grazing management practices on soil seed bank replenishment under Syrian arid rangeland conditions?*

- ➢ *Research question 3: Is the Bayesian approach for diversity estimation comparable to the traditionally used frequentist approaches?*

Seeds of range shrubs are produced under harsh conditions and poor management practices using the opportunistic approach of hand-picking from the naturally or artificially protected areas, stored and planted without proper cleaning. Moreover, range plant species have not been subjected to high selection pressure, thus they still possess the survival mechanisms such as uneven maturity and dormancy known in wild plants. Consequently, the percentages of pure live seed, viability and germination capability in the bulk of raw material vary significantly depending on the season, areas of collection, time and method of harvesting and species (Von Holdt, 2000). Hence, investigation of effective seed processing and standardized seed quality control methods before planting is crucial for proper selection of appropriate seed lot, determination of appropriate seeding rate to achieve good crop establishment and optimum plant density. Moreover, seed productivity, quality and longevity are limited by adverse weather conditions and ambient storage; especially in species such as *Salsola vermiculata* L., thus cost-effective storage conditions that maintain viability and longevity of seed stocks for longer periods are crucial for rangeland rehabilitation. Seed productivity and quality are affected by the erratic climatic conditions of the arid Mediterranean rangelands, thus seed quality monitoring, maintenance and promotion of longevity are crucial for range rehabilitation and revegetation programs.

- ➢ *Research Question (4): Which of the seed quality promotion and maintenance of longevity method(s) is necessary and works best for Salsola vermiculata L. used in the range revegetation programs implemented in the Syrian arid Mediterranean rangelands and beyond?*

Chapter 2

Impacts of grazing management on vegetation cover in the Mediterranean type climate of northern Syria

This chapter has been submitted to *The Journal of Arid Environments* as:

Impacts of grazing management on Vegetation Cover in the Mediterranean Type Climate of Northern Syria

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Chapter 2. Impacts of grazing management on vegetation cover in the Mediterranean type climate of northern Syria

Abstract

Rangelands are important for providing forage to grazing sheep in Syria. Overgrazing however causes rangeland degradation. This is mitigated by large-scale rehabilitation consisting of shrub transplanting, protection and rotational grazing. In this study ten rehabilitation sites with full protection (FP), rotational (RG) and continuous grazing (CG) treatments were evaluated during three consecutive seasons using quadrat (QD) and point intercept (PI) data collection methods to assess the impact of rehabilitation on plant density, plant community composition, species richness and diversity.

ANOVA on overall plant density and richness data showed significant grazing-by-site interaction. The interaction resulted from higher plant density under continuous grazing than full protection in one out of the ten sites studied, due to frequent opportunistic barley cultivation leading to increase in the weed population. For the nine sites, plant density consistently increased from CG to FP along the grazing gradient in which the trend of change in species richness and diversity was not consistent.

Pair-wise comparison on the life span functional group data, showed that plant density of perennial grasses and overall species diversity indices was lowest under rotational grazing, showing a shaping-up effect of grazing on plant community composition. The lower species diversity under RG is probably due to more geophytes resulting from less exposure of bulbs and rhizomes due to less soil erosion under RG than under CG and fewer rodents feeding on the bulbs than under FP with more shelter.

Tests of similarity using Morisita-Horn and Sørensen abundance based species richness showed high similarity in species richness between the three grazing treatments, implying that rehabilitation did significantly shift species dominance but not yet changed the plant community composition.

The coefficients of determination for plant density was positive and significant ($P \leq 0.05$) with observed species richness but not with species diversity.

For the current arid Mediterranean rangeland rehabilitation programs to cross the line of no return, incorporation of inter-seasonal grazing and herbivore variation seem to be necessary.

Keywords: rotational grazing, full protection, continuous grazing, plant density, richness, diversity indices

1. Introduction

Grazing is a common denominator in all rangeland definitions and rangeland management options. Since the beginning of rangeland management as a science and art (Holechek, 1981), comprehensive research findings have been published on the effects of trampling on range ecosystem components such as soil biophysical properties and seed bank (Stavi et al., 2011; Verhoustraeten & Baur, 2011; Huang et al., 2007); soil organic matter, moisture and nutrient contents (Schlecht et al., 2011; Snyman & Preez, 2005); vegetation cover dynamics and relative abundance of plant species and plant functional groups such as decreasers, increasers, and invaders (O'Connor et al., 2011; Mosallam, 2007; SRM, 1995).

Overgrazing refers to the imbalance between stocking rate, timing, continuity, herbivore type, nomadism and rangeland carrying capacity. Behnke & Abel (1996) proposed different stocking targets to different husbandry practices and objectives instead of single optimum stocking density. Many rangelands suffer from overgrazing which is considered a major cause of degradation in the semi-arid and arid areas of the Mediterranean region and beyond (Louhaichi et al., 2012; Cesa & Paruelo, 2011; Boyd & Svejcar, 2009; Belgacem et al., 2008). On the other hand, grazing management is the key to rangeland recovery (Rossignol et al., 2011; El-keblawy et al., 2009; Gallacher & Hill, 2006; Nooralhamad, 2006). Full protection and rotational grazing are major components of most, if not all, rangeland rehabilitation programs in the semi-arid and arid Mediterranean region and beyond (Belgacem et al., 2008; Gintzburger et al., 2005; Teague, 2004). Nevertheless, systematic studies to evaluate the long-term effects of extensive range rehabilitation programs, which usually consist of planting halophyte shrubs and introducing rotational grazing, on species abundance, richness, diversity and interrelationships are still limited in the semi-arid and arid Mediterranean rangelands, particularly Syria.

In Syria, arid rangelands represent 55% of the total land area and are a major source of free feed for 15 million heads of sheep (FAO, 2006; ACSAD, 2004). A large-scale rehabilitation program covering more than 100,000 ha of the arid Mediterranean rangelands of Syria has been implemented over the last five decades (Mundy & Musallam, 2003; Mourad et al., 2000; Jaubert et al., 1999). The program has been implemented by means of planting halophyte shrubs, and introducing protection and rotational grazing. Apart from a recent survey of range resources in the Syrian steppes by the Arab Center for the Study of Arid Zones and Dry Lands (ACSAD, 2004), research on the impacts of the large scale rehabilitation programs on range floral dynamics and the implications for rangeland recovery are limited. In a study on arid land management in Syria, Rae et al. (2001) argued that the link made between signs of degradation and perceived moribund customary systems is not at all causal. The rangeland rehabilitation programs in the arid Mediterranean areas are based on the assumptions that rangeland degradation is caused by overgrazing, thus resting (protection), rotational grazing and transplanting are the ways to recovery. This study is to quantify the impacts of overgrazing on the above-ground vegetation abundance, richness and species diversity and their interrelationship under the five-decade long Syrian range rehabilitation programs.

2. Material and methods

2.1. Study site

The study was carried out in the cool arid Mediterranean type rangelands in the northwest of Syria (Fig. 1), with high temperature amplitudes, low annual rainfall (≤200 mm) and a long dry season (Figs 2 and 3). The study sites are located between 34°.13' and 35°.66' N and 37°14' and 37°.85' E (Fig. 1).

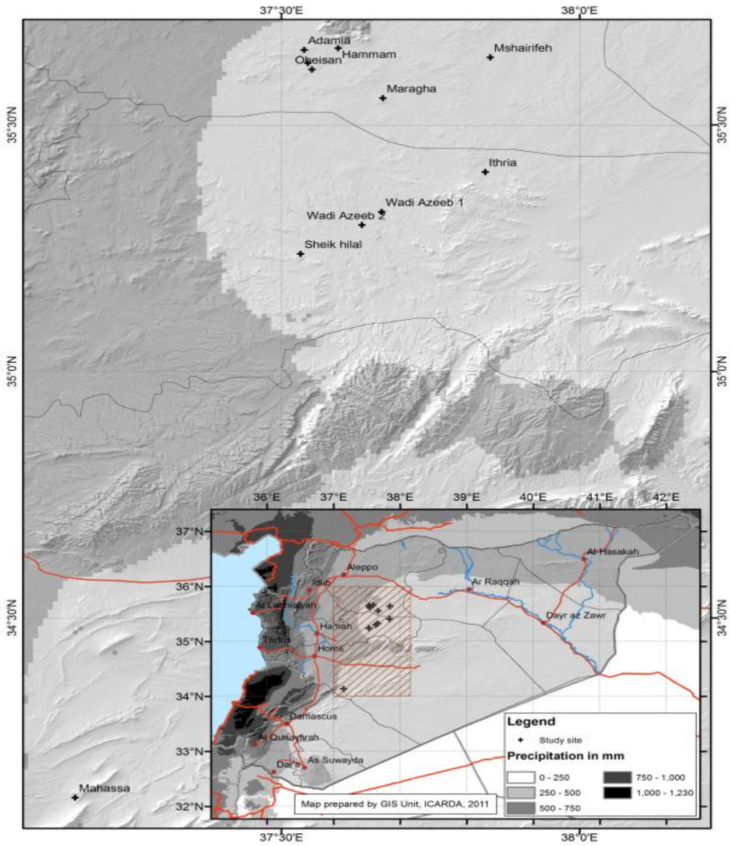

Figure 1: Precipitation map of Syria showing the study sites under 0-250 rainfall area. Map provided by the ICARDA GIS unit

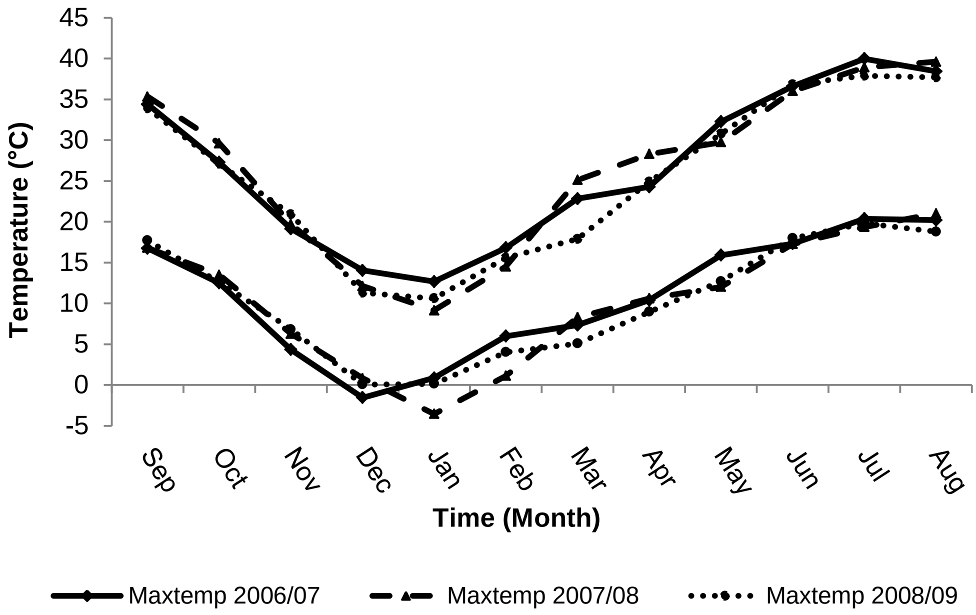

Figure 2: Maximum and minimum monthly temperature during 2006/07, 2007/08 and 2008/09 in the study sites

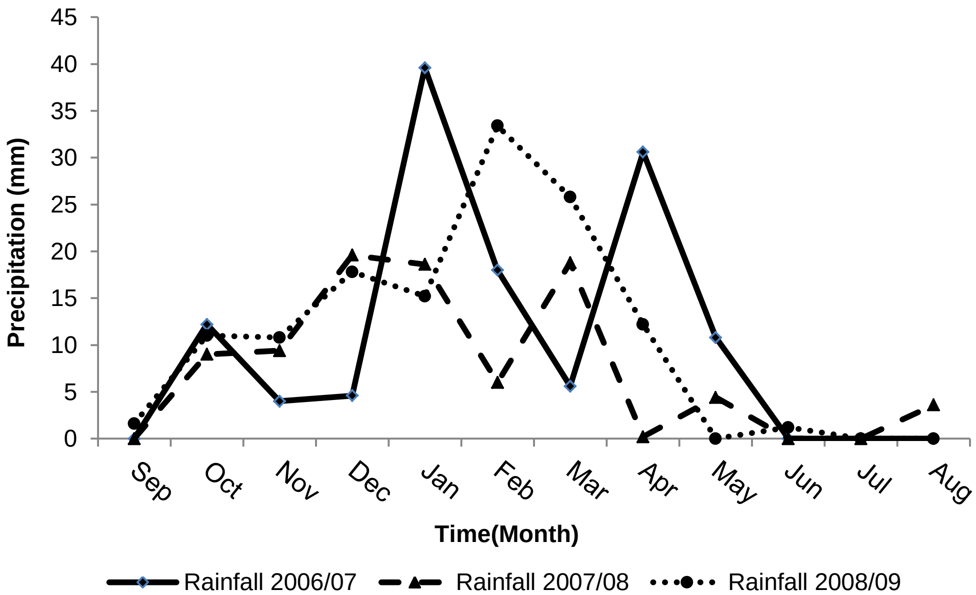

Figure 3: Mean monthly precipitation of the study sites during 2006/07, 2007/08 and 2008/09

The study was carried out within 10 range reserves established and managed by the Syrian Steppe Directorate using halophytes shrub transplanting and rotational grazing (Figs 4 and 5). *Atriplex spp.* particularly halimus are the major species used in the rehabilitation programs. Fully protected areas established within eight of them for range monitoring purposes were used in the study (Table 1). The oldest range reserves were established in the 1950s at Wadi Azeeb1 and the remaining were established after the 1980s (Jaubert et al., 1999; Mourad N.: In Gintzberger et al., 2000).

Table 1: Range sites, years of protection and grazing treatments, Northern Syria

Provinces	Sites	Years of protection	Shrub planting	Anthropogenic factors[1]	Grazing treatments[2]	Study seasons[3]
Aleppo	Obeisan	0	No	1, 4	Continuous	3
		20	Yes	1, 4	Protected	3
		20	Yes	1, 4	Rotational	3
	Adamia	0	No	1, 2	Continuous	3
		10	Yes	1, 2	Protected	3
		10	Yes	1, 2	Rotational	3
	Hammam	0	No	1, 2	Continuous	3
		5	No	1, 2	Protected	3
		5	No	1, 2	Rotational	3
	Wadi Azeeb1	0	No	1, 2, 3	Continuous	3
		40	Yes	1, 2, 3	Protected	3
		40	Yes	1, 2, 3	Rotational	3
	Wadi Azeeb2	0	No	2	Continuous	3
		5	Yes	2	Protected	3
	Maragha	0	No	1, 2	Continuous	3
		20	Yes	1, 2	Rotational	3
	Mshairifeh	0	No	1, 4	Continuous	3
		20	Yes	1	Rotational	3
Hama	Ithria	0	No	1, 2, 3	Continuous	3
		40	Yes	1, 2, 3	Protected	3
	Sheik hilal	0	No	1, 2	Continuous	2
		5	Yes	1, 2	Protected	2
Homs	Mahassa	0	No	2	Continuous	2
		5	Yes	2	Protected	2

[1]: Numbers represent anthropogenic factors as follows: 1 = near people and animal agglomerations; 2 = near main road; 3 = near water point; 4 = cultivation. [2]: 0.03 m^3 of soil from 9 cores of 20 cm diameter and 10 cm depth on 3 transects of 100 m long, each were collected annually from every grazing treatment. [3]: Data collection during 2006/07, 2007/08 and 2008/09.

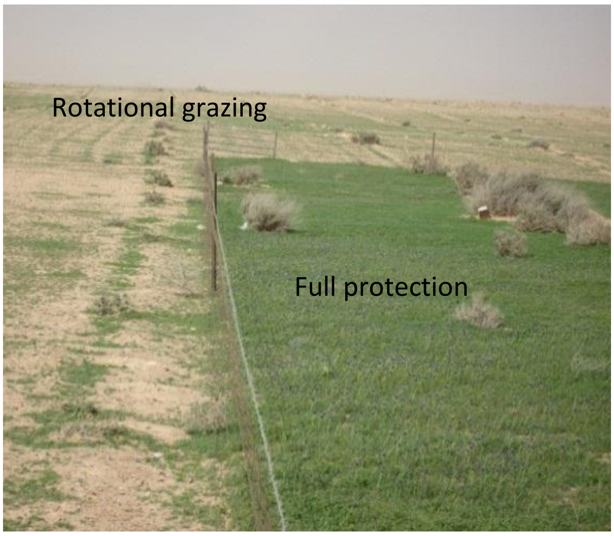

Figure 4: Arid rangeland sites under full protection and rotational grazing in northern Syria (spring)

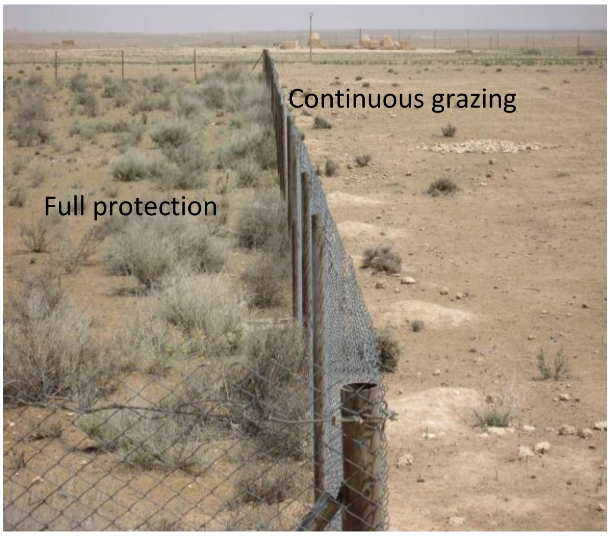

Figure 5: Study sites under full protection and continuous grazing in northern Syria (summer)

2.2. Grazing treatments

About 5-10 ha plots each were demarcated within and outside each of the fences of the fully protected and rotationally grazed areas of the 10 range reserves surveyed. The demarcated plots represented the survey treatments of protected, rotational and continuous grazing. Non-representative areas such as water points and high traffic passages were avoided as much as possible. The grazing pressure in the rotational grazing areas was estimated based on the average site carrying capacity of 3 sheep/ha for 90 days/year. Rapid carrying capacity estimation of the fully protected and the rotationally grazed areas in autumn and spring are part of the rangeland rehabilitation program. The data collected is used to determine the carrying capacity of the rangeland reserves and adjacent areas at the time of opening. Review of the data showed that the grazing pressure in the open areas was far beyond the actual carrying capacity of the area estimated at 3 sheep/ha for 90 days/year.

2.3. Soil analyses

Two soil samples at 20 cm depth were collected from each of the 10 sites to determine salinity, extractable potassium, organic matter content, phosphorus, clay, silt and sand (Table 2).

Table 2: Soil physic and chemical analysis results of the ten studied rangeland sites in Northern Syria

Sites	EC_e mS/cm [1]	Extr. K ppm [2]	OM [3] (%)	P (ppm)	Clay (%)	Silt (%)	Sand (%)	Soil texture
Adamia	7.9	542	2.85	14.5	20.4	60.0	19.7	Silt loam
Hammam	8.1	190	2.10	3.2	7.8	58.3	33.9	Silt loam
Ithria	2.5	871	2.35	17.0	35.1	42.3	22.7	Clay loam
Maragha	7.2	862	3.15	20.5	19.1	62.4	18.6	Silt loam
Mshairifeh	7.0	788	2.10	10.0	5.6	75.3	19.2	Silt loam
Obeisan	8.3	909	3.70	26.5	8.0	63.4	28.6	Silt loam
Wadi Azeeb1&2	3.5	569	2.40	17.5	20.2	39.4	40.5	Loam
Mahassa	6.7	8	1.06	7.6	15.6	17.5	66.9	Sandy loam
Sheikh hilal*	2.0	6	1.12	7.0	23.4	13.6	63.0	Sandy clay loam

[1] EC_e: electrical conductivity in micro Siemens per centimeter; [2] Extr. K: extractable potassium in part per million; [3] OM: soil organic matter; Phosphorus in part per million.

2.4. Data collection and summarizing

From each grazing treatment, quantitative data on number of individual plant species were collected using 1 m × 1 m quadrat (Nooralhamad, 2006; Kercher et al., 2003) and point intercept (Barabesi & Fattorini, 1998; Harold et al., 1959). A total of nine quadrats and 300 points on three 100 m long transects, were collected from each grazing treatment each year over the three seasons of study (2006/07, 2007/08 and 2008/09). The three transects were in the form of a radius starting from a central point of each macro plot going in opposite directions with approximate angles of 120 degrees between them. There was non-intentional overlapping in some starting points, positions of point intercepts and quadrats in different years. The sampling was carried out in April each season, at the peak of flowering time to capture the maximum richness and population density and to facilitate plant identification. On each of the three radii of 100 m long transects, plants, plant litters, gravel and bare ground were recorded on 100 point intercepts. In addition, plant species density and frequencies were also recorded on three quadrats of 1 m^2 on each of the three radii. In total, 300 point intercepts and 9 quadrats were recorded from each grazing treatment each season (Table 1). The process was repeated in each of the treatments over the three consecutive seasons. The two data collection methods namely quadrat and point intercept were used to explore their relative power differences to capture grasses and shrubs and in generating suitable data for species abundance and richness. To establish the composition of the plant communities under different grazing treatments, the observed plants were identified based on Sankary (1977) and Zohary (1962) with expert assistance from the range ecologists of the International Center for Agriculture Research in the Dry areas (ICARDA) and the Syrian Steppe Directorate.

In a sampling unit, the total number of individual plants or stems from all the species and the total number of the observed species are referred to as plant density or abundance and species richness, respectively. Plant species frequency refers to the ratio between the number of sample units that contain a species and the total number of sample units, whereas relative density of a species is the ratio of its individual numbers and the total number of individuals from all the species recorded. Plant community refers to the assemblage of plants occurring together at each research site (SRM, 1995), while the composition is about the relative frequency and density of the most common plant species.

Species diversity was established based on the recorded species abundance and observed richness using the Shannon-Wiener, Simpson and the expected number of Singleton equations (Neuteboom & Struik, 2005; Magurran, 2004; 1983). The Shannon's index of diversity (H) for a sample is the average degree of uncertainty in predicting the species of an individual chosen at random from a sample (Spellerberg & Fedor, 2003) whereas Simpson's index (D) for a sample is the probability that two individuals selected at random are from the same species (Magurran, 2004); the expected number of singleton species (S_{n1}) refers to the number of species present with one individual in an infinitely large sample (Neuteboom & Struik, 2005a).

Mean species frequency and density for different grazing methods were calculated from the summary tables of the flora studies and subjected to analysis of variance to test the relative efficiency of the data collection methods used in capturing different life span plant groups (Annexes A, B, and C).

2.5. Data analysis

The data collected were used to generate species frequencies, plant density, species richness and diversity indices using Shannon-Wiener, Simpson reciprocal indices (Magurran, 2004; 1983) and expected number of singleton species (Neuteboom & Struik, 2005a,b) at overall flora and functional group levels. The above parameters were disaggregated based on quadrat and point intercept data collection methods and subjected to five methods of statistical analysis:

a. Unbalanced accumulated analysis of variance in a completely randomized design with no blocking and year, site and grazing as treatment structure. This was to test the main effects and interactions of grazing, site and year.
b. Pair-wise comparison of grazing treatments' effects on **functional group plant density** using Generalized Linear Model (GLM) with Poisson link. Pair-wise comparison was used to focus the analysis on the effects of grazing on the functional groups.
c. Pair-wise comparison of **Shannon-Wiener and Simpson reciprocal indices of diversity** for grazing treatments within sites disaggregated by quadrat and point intercept methods using *t-tests* (Magurran, 1988; Johnson & Kotz, 1969) (Annex 1).
d. Correlation tests to assess interdependence between plant population parameters namely density, richness and diversity indices under grazing treatments within and between sites over years.
e. Morisita-Horn and Sørensen similarity tests to assess changes in plant population composition as measured using quadrat and/or point intercept methods within and between sites over years.

The mathematical equations based on which the pair-wise comparison code was developed were as follow:

The standard Simpson's index (D) of diversity equation used is: $D = \sum_{i=1}^{s} p_i^2$. The Simpson index of diversity (SID) form (1/D) was adopted (Magurran, 2004) as below

$$\frac{1}{D} = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

where p = weighted arithmetic mean of the proportional abundances.

To establish the statistical precision and make comparison between treatments, the indices of diversity for the plant functional groups recorded, their standard variances and errors were calculated as shown below (Magurran, 1988). The standard error of SID is the same as standard error of D. Thus SE (SID) $=\sqrt{Var(D)}$, where the variance of D is obtained as follows:

$Var\,(D) = \sum_{i=1}^{s} Var\,(p_i^2) + 2\sum_{i>j}^{s}\sum COV(p_i^2, p_j^2) = \sum_{i=1}^{s}[\mathrm{E}(p_i^4) - \{\mathrm{E}(p_i^2)\}^2] + 2\sum_{i>j}^{s}\sum[\mathrm{E}(p_i^2\,p_j^2) - \mathrm{E}(p_i^2)E(p_j^2)]$

where E (.) stands for the expectation of the variable in the parenthesis. We note that the random distribution of (a_1, a_2,….a_i) is generally assumed to follow a multinomial distribution, thus using the results of factorial moments and raw moments (Johnson & Kotz, 1969), the estimates can be derived as follows:

$Est.E(p_i^2) = p_i^2 + \frac{pi(1-pi)}{N} = p_i^2 + pi(1-pi)l$, where l =1/N

$$Est.\,\mathrm{E}(p_i^2 p_j^2) = (1-l)(1-2l)(1-3l)p_i^2 p_j^2 + (1-l)(1-2l)lpipj(pi+pj) + (1-l)l^2 pipj$$

For i ≠ j, the estimated variance of D is

$$EST\ Var(D) = \sum_{i=1}^{s}[Est\ \mathrm{E}\,(p_i^2) - \{Est\ E(p_i^2)\}^2] + 2\sum_{i>j}^{s}\sum[Est\ E(\,p_i^2, p_j^2) - Est\ E(p_i^2)Est\ E\ p_j^2)]$$

For expected number of singleton species, the calculations are made using the following equation:

$E(S) = \sum_{n=i}^{N=\infty} E(S(n))$ where *E(S)* stands for the total number of species expected $E(S)$ in an indefinite large sample N=∞ predicted from observed number of species referred to as $(n = i)$.

To establish an association between plant community components, the plant density, species richness and indices of diversity generated were subjected to correlation and similarity tests. The correlation coefficients were generated using the Version 2009.1.02 of Xlstat whereas; the similarity indices were generated using the Sørensen and Morisita-Horn equations (Magurran, 2004). The equation of Sørensen quantitative index (abundance data) is $C_N = 2jN/((aN + bN))$ where $_aN$ is the total number of individuals in site A, $_bN$ the total number of individuals in site B and jN= the sum of the lower of the two abundances for species found in both sites. For Morisita-Horn index (abundance data), the equation used is:

$$C_{mH} = \frac{2\sum(ai.bi)}{(d_a + d_b) * (N_b * N_b)}$$

where N is the total number of individuals at site A and a*i* is the total number of individuals at site in the i*th* species in A. $d_a = \frac{\sum a_i^2}{N_a^2}$.

3. Results

3.1. Plant density

The results showed a decline in plant density from FP to CG. Mean plant density of annuals by quadrat (QD) sampling under full protection (FP), rotational grazing (RG) and continuous grazing (CG) was 52, 29 and 28 per 9 m^2 respectively, whereas by point intercept (PI) it was 33, 37 and 34 per 300 m long transect. For perennials, the mean plant density by QD under FP, RG and CG was 370, 412 and 240 per 9 m^2, respectively, whereas by PI it was 12.1, 10.5 and 9.8 per 300 m long transects.

The mean relative plant density measured using quadrat and point intercept methods showed significant method by life span interaction (Fig. 6). This indicated significant differences in efficiency of the two data collection methods used in capturing different types of plant functional groups.

Unbalanced design regression made on overall plant density of individual grazing treatments within sites using point intercept method with year, site and grazing as main factors in a completely randomized arrangement showed significant (P<0.01) grazing by site interaction on percentage green cover (Fig. 7). Except for Mshairifeh and Maragha, percentage green cover significantly declined from FP to CG. Moreover, the variance ratios and F-probabilities from ANOVA (Table 3) showed that year was the most important source of variations followed by site and then grazing treatments.

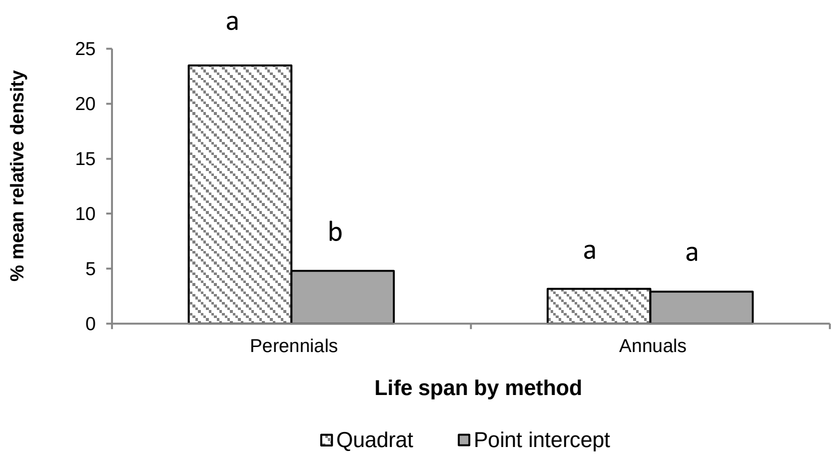

Figure 6: Mean relative density of annual and perennial plants recorded using quadrat and point intercept methods. Different letters indicate significant differences in mean relative frequencies

Interaction of grazing by site was significant (P<0.05) for plant density (Table 3). In both methods of sampling, mean plant density for the overall plant population, consistently and significantly (P<0.01) declined along the grazing gradient within most of the study sites from FP to RG then CG. Nonetheless, the differences were not significant for all sites and in Mshairifeh the direction of decline was opposite to that of the grazing intensity gradient (Figs 7, 8 and 9).

Table 3: ANOVA table for plant density, species richness and diversity indices for different grazing management and seasons

Sampling Methods	Factors	d.f.	Density Var. ratio	Density F pr.	Richness Var. ratio	Richness F pr.	Shannon Var. ratio	Shannon F pr.	Simpson Var. ratio	Simpson F pr.	Singletons Var. ratio	Singletons F pr.
	Site	9	22.90	<.001	13.89	<.001	1.56	0.188	0.96	0.494	0.67	0.727
	Year	2	21.04	<.001	110.31	<.001	14.08	<.001	7.91	0.003	2.26	0.132
	Grazing	2	10.01	<.001	5.88	0.009	2.81	0.082	1.19	0.322	1.59	0.231
Quadrat	Site.Year	16	2.59	0.020	8.03	<.001	0.97	0.518	0.81	0.66	0.4	0.965
	Site.Grazing	12	2.30	0.043	8.23	<.001	1.57	0.174	1.22	0.331	0.86	0.593
	Year.Grazing	4	0.79	0.542	0.61	0.66	0.94	0.46	0.47	0.755	0.16	0.954
	%CV		34.3		16.1		29.9		50.8(22.7)*		67.1(36.4)*	
Point intercept	Site	9	7.34	<.001	9.88	<.001	0.56	0.811	0.78	0.635	1.71	0.158
	Year	2	26.53	<.001	34.6	<.001	10.88	<.001	8.03	0.002	3.01	0.075
	Grazing	2	9.52	0.001	0.67	0.520	1.34	0.282	0.68	0.517	1.9	0.178
	Site.Year	16	2.20	0.044	4.42	<.001	2.01	0.064	1.10	0.407	2.87	0.017
	Site.Grazing	12	2.33	0.041	2.77	0.018	0.74	0.702	0.35	0.969	1.22	0.343
	Year.Grazing	4	0.53	0.712	2.43	0.078	1.01	0.425	0.65	0.631	2.55	0.075
	%CV		18.2		17.6		18.1		41.7(21.5)*		37.1 (27.8)*	

*: Between brackets: The analysis is based on original data and %CV based on square root transformation

Var.: Variance

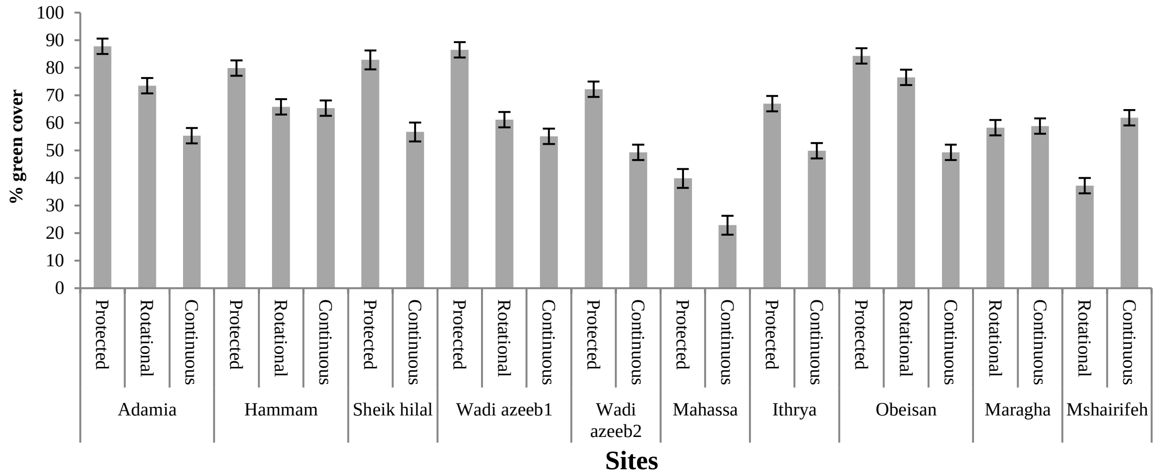

Figure 7: Percentage green cover for different grazing treatments within different sites with standard error bars of means

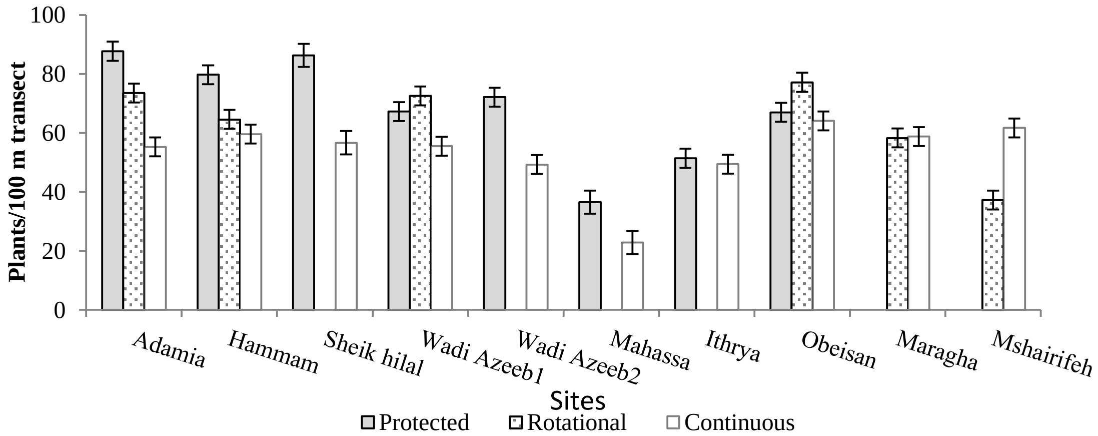

Figure 8: Changes in overall plant density measured using quadrat across a grazing gradient within 10 rangeland sites in Northern Syria averaged over three consecutive seasons with standard error bars of means

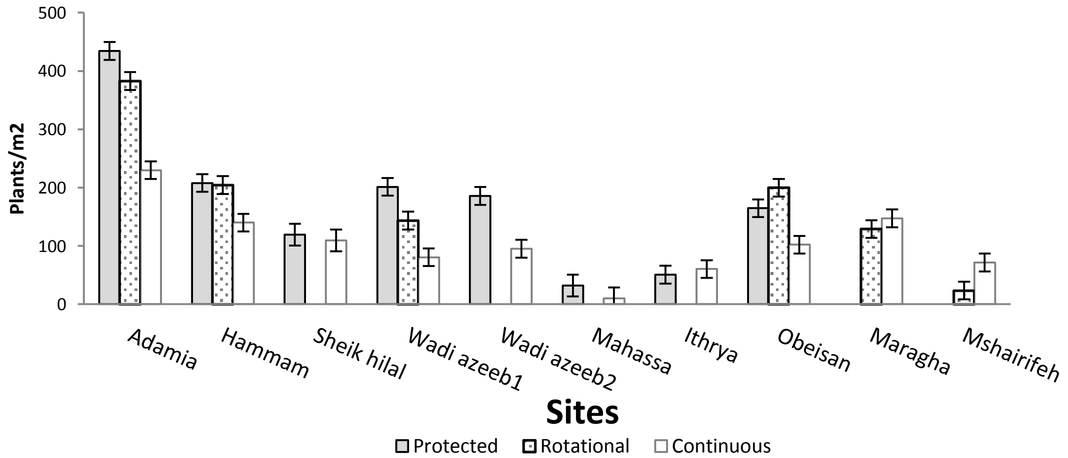

Figure 9: Changes in overall plant density measured using point intercept across a grazing gradient within 10 rangeland sites in Northern Syria averaged over three consecutive seasons with standard error bars of means

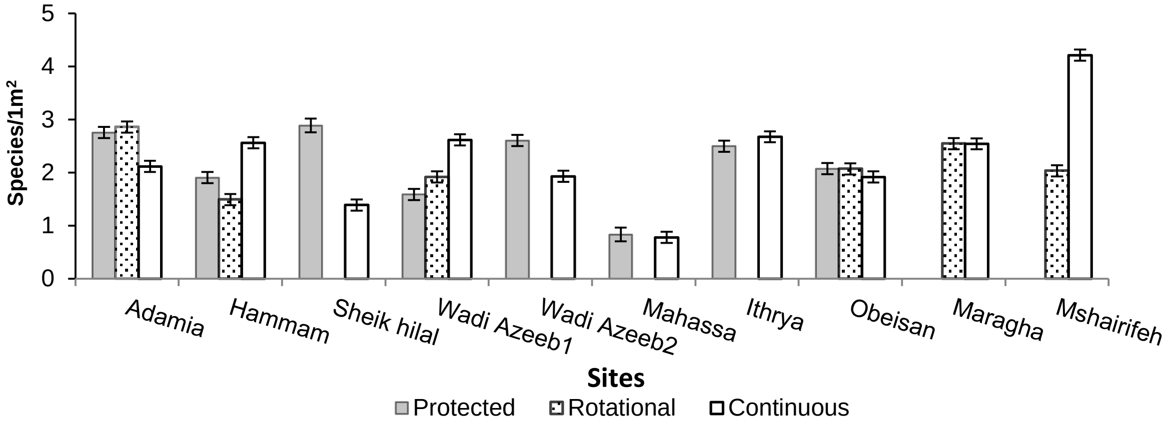

Figure 10: Species richness measured using quadrat method across a grazing gradient within 10 rangeland sites in Northern Syria averaged over three consecutive seasons with standard error bars of means

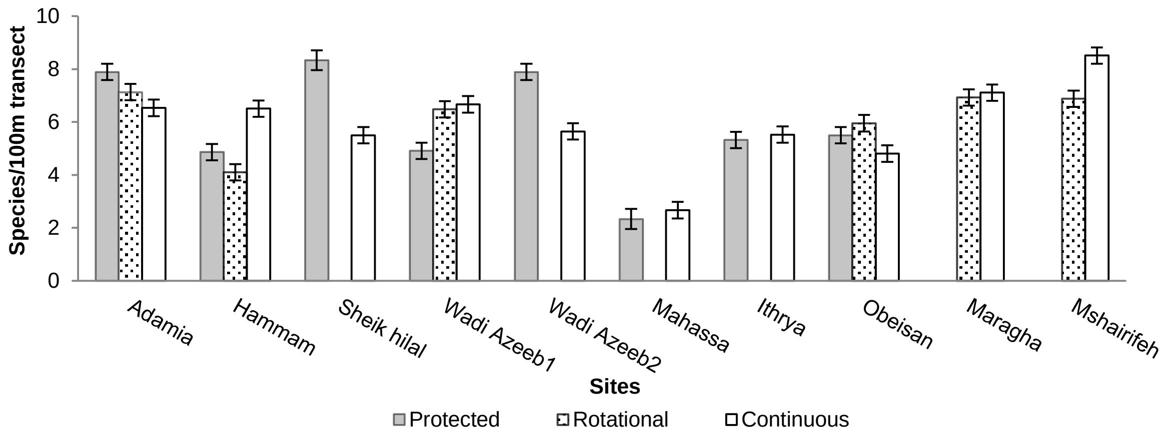

Figure 11: Species richness measured using point intercept method across a grazing gradient within 10 rangeland sites in Northern Syria averaged over three consecutive seasons with standard error bars of means

The GLM analysis results on plant density of life span functional group showed that annual forbs measured by quadrat and point intercept significantly declined along the grazing intensity gradient from FP to RG then CG whereas the annual grasses were highest under FP and lowest under RG. For the perennials, plant density of forbs was highest under CG and lowest under RG whereas the grasses followed the opposite direction. The density of shrubs declined along the grazing intensity gradient for the point intercept measurements and irregular for the quadrats. The plant density of most life form functional groups followed similar trends to that of the overall plant density significantly declining along the grazing intensity gradient. The plant density of the geophytes was higher under RG and lowest under CG in most cases. The trend of decline in density was towards the intensity grazing gradient for the palatability groups (Table 4).

Table 4: Mean of plant density along grazing gradients within 10 rangeland sites in northern Syria assessed by quadrat and point intercept over three consecutive seasons

Sampling method	Functional group	2006/07			2007/08			2008/09		
		Closed	**Managed**	**Open**	**Closed**	**Managed**	**Open**	**Closed**	**Managed**	**Open**
Quadrat	**Life span**									
	Annual forb	598.8±10.0^{a}	410±8.3^{b}	400.6±7.1^{b}	136.9±4.4^{b}	143±4.9^{b}	195±4.7^{a}	678.2±9.2^{a}	439.5±8.6^{b}	396.9±6.3^{c}
	Annual grass	156.2±5.1^{a}	34.5±2.4^{c}	56.8±2.7^{b}	64.2±3.3^{a}	7.3±1.1^{c}	30.8±2.3^{b}	168.5±4.6^{a}	138.8±4.8^{b}	116.6±3.6^{c}
	Perennial forb	24.8±2.3^{b}	13.8±1.5^{c}	54.3±3.0^{a}	4±0.9^{c}	19.6±2.0^{b}	34±2.4^{a}	13.1±1.4^{b}	14.7±1.6^{b}	33.3±2.0^{a}
	Perennial grass	1614.2±16.4^{a}	1622.6±18.0^{a}	971.7±12.7^{b}	1098.8±13.5^{b}	1244.6±15.8^{a}	305.1±5.8^{c}	1044.4±12.2^{a}	1030.2±13.1^{a}	736.4±9.6^{b}
	Shrub	32.7±2.3^{b}	50±2.9^{a}	33.1±2.0^{b}	15.5±1.4^{a}	13.3±1.5^{a}	20.8±1.5^{a}	27.5±1.9^{b}	40.2±2.6^{a}	47.1±2.4^{a}
	Life form									
	Chamaephyte	23.2±2^{b}	35±2.4^{a}	28.4±1.9^{ab}	15±1.4^{a}	11.7±1.4^{a}	17.4±1.4^{a}	15.1±1.5^{b}	23.7±2^{b}	45.6±2.5^{a}
	Hemicryptophyte	809.2±11.6^{a}	534.3±9.4^{b}	342.1±7^{c}	504.5±7.9^{b}	540.2±9.5^{a}	231.6±5.1^{c}	552.5±8.3^{b}	603±10^{a}	351.8±6.3^{c}
	Geophyte	921.8±12.4^{b}	1031±14.4^{a}	570.9±9^{c}	444.9±8.5^{b}	774.8±13.9^{a}	172±5.4^{c}	599.9±9.3^{a}	473.2±8.9^{b}	381.6±6.5^{c}
	Therophyte	668.3±10.6^{a}	431.3±8.5^{b}	432.4±7.4^{b}	179.3±5.1^{a}	148.2±5^{b}	200.4±4.7^{a}	709±9.4^{a}	559.2±9.7^{b}	463.3±6.8^{c}
	Phanerophyte	2.4±1.4^{a}	4±2^{a}	0±0^{b}	4.8±4.4^{a}	0±0^{b}	0±0^{b}	15.4±12.4^{a}	0±0^{b}	0±0^{b}
	Palatability									
	High	975.2±12.7^{a}	724±11^{b}	391.9±7^{c}	544.3±8.2^{a}	566.7±9.7^{a}	203.9±4.5^{b}	828.4±10.2^{a}	868.8±12^{a}	504.3±7.5^{b}
	Medium	940.8±12.5^{a}	853.5±11.9^{b}	496.6±7.9^{c}	457.4±8.7^{b}	772.8±13.9^{a}	164.9±4.9^{c}	596.4±9.2^{a}	576±10.7^{a}	487.1±8.3^{b}
	Low	506.5±9.2^{a}	283±6.9^{b}	371.5±6.8^{c}	122.8±3.9^{b}	135.3±4.7^{b}	188.4±4.3^{a}	449.4±7.5^{a}	314.5±7.2^{c}	360.3±6^{b}
Point intercept	**Life span**									
	Annual forb	76.5±3.6^{a}	58.8±3.1^{b}	53.1±2.6^{b}	64±2.8^{a}	51.2±2.9^{ab}	47.7±2.2^{b}	131.3±4.1^{a}	106.8±4.2^{b}	100.9±3.2^{b}
	Annual grass	22.7±1.9^{a}	16.3±1.6^{b}	19.4±1.6^{a}	22.3±1.9^{a}	6.2±1^{b}	8.9±1.1^{b}	39.6±2.2^{a}	28±2.1^{b}	38.6±2.1^{a}
	Perennial forb	7.6±1.2^{ab}	3.8±0.799^{b}	9.1±1.1^{a}	7.9±1.1^{a}	8.8±1.3^{a}	11.4±1.2^{a}	10.2±1.3^{a}	7.8±1.1^{a}	13.6±1.3^{a}
	Perennial grass	74.2±3.5^{a}	57.6±3.4^{a}	35.4±2.3^{b}	67±3.3^{b}	94.6±4.4^{a}	29±1.7^{b}	28.3±1.9^{b}	54.6±3.3^{a}	31.7±2.1^{b}
	Shrub	43±2.7^{a}	26±2.1^{b}	25.1±1.8^{b}	82.8±3.2^{a}	38.3±2.5^{c}	52.9±2.4^{b}	32.8±2^{a}	29.8±2.2^{a}	29.1±1.8^{a}
	Life form									
	Chamaephyte	41.7±2.6^{a}	20.2±1.8^{b}	21.4±1.6^{b}	67±2.9^{a}	35±2.4^{b}	46.2±2.3^{b}	24.9±1.9^{a}	24.8±2^{a}	26.1±1.8^{a}
	Hemicryptophyte	51.8±2.9^{a}	32.7±2.3^{b}	29.4±1.9^{b}	47.9±2.4^{a}	59.2±3.1^{a}	40.5±2^{b}	46.8±2.4^{a}	41.7±2.6^{a}	37.1±1.9^{a}
	Geophyte	43±2.7^{a}	26±2.1^{b}	23.3±2^{b}	24.7±2^{a}	36.4±2.7^{a}	11.3±1.3^{b}	31±2.3^{a}	22.2±1.9^{ab}	17.1±1.4^{b}
	Therophyte	85.5±3.8^{a}	71.2±3.4^{ab}	68.4±2.9^{b}	76.9±3.1^{a}	55±3^{b}	49.6±2.2^{b}	147.1±4.3^{a}	127±4.6^{ab}	121.5±3.5^{b}
	Phanerophyte	1.3±0.7^{a}	6±1.4^{a}	0±0^{b}	41.5±4.6^{a}	3.5±0.9^{b}	0±0^{c}	1.7±0.7^{a}	7±1.9^{a}	0±0^{b}
	Palatability									
	High	119.7±4.5^{a}	87.5±3.8^{b}	58.9±2.7^{c}	93.5±3.4^{a}	92.7±3.9^{a}	53.3±2.3^{b}	108.3±3.7^{a}	110.7±4.3^{a}	92.3±3.2^{a}
	Medium	46.2±3^{a}	25.8±2.1^{b}	23.4±1.8^{b}	48.3±4^{a}	41.5±3.2^{a}	14±1.3^{b}	30±2.2^{a}	24.3±2^{a}	22.8±2^{a}
	Low	64.5±3.3^{a}	39.7±2.6^{c}	57.3±2.7^{a}	109±3.7^{a}	61.5±3.2^{b}	75.1±2.7^{b}	108.8±3.7^{a}	83±3.7^{b}	98.1±3.1^{b}

Standard errors with values less than 0.01 are kept as zero

3.2. Plant species richness and diversity

The results showed that 121 taxa of 97 genera from 34 families including both annuals and perennials were found in the study sites. The most common taxa captured in both sampling methods were 79 annuals and 32 perennials. The total number of annual and perennial species recorded was 37 and 20 by QD and 38 and 18 by PI. The relative frequencies of annuals under FP, RG and CG by QD were 33.5%, 38.4% and 34.7% and by PI were 10.6%, 7.0% and 6.2%, respectively. For perennials, the frequencies under FP, RG and CG by QD were 26%, 29.7% and 27.0% and by PI were 35.8, 38.9 and 32.7%, respectively. The change in relative species frequency, as shown above did not show constant trends. Moreover, no significant differences were found in mean numbers of annual and perennial plant species from both sampling methods under the three grazing treatments.

Variance ratios and F-probabilities from ANOVA (Table 3) showed that for species richness, year was the most important source of variation followed by site then grazing practices. Significant year-by-site and grazing-by-site interaction for QD and PI measurements (Table 3) indicated changes in the ranking of species richness of the grazing treatments among the 10 range land sites surveyed (Figs 10 and 11).

Significant ($P<0.01$) interaction of sampling method by life span was observed indicating differences in efficiency of the methods used in capturing plants from different functional groups (Fig. 12). The differences in mean relative species frequency among grazing treatments were not significant.

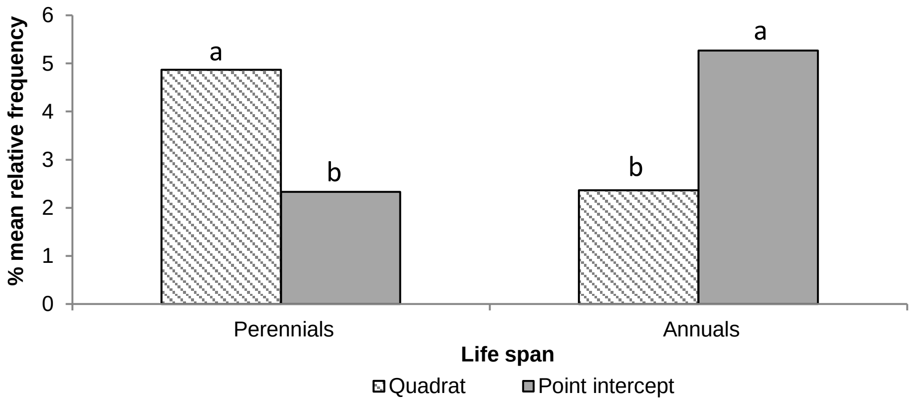

Figure 12: Mean relative frequency of annual and perennial plants recorded using quadrat and point intercept methods. Different letters indicate significant differences in mean relative frequencies

Pair-wise comparison showed that mean overall plant species richness and diversity indices were lowest under RG compared to both FP and CG. In most cases, the diversity indices were higher under CG than FP. For the point intercept measurements, the species diversity was higher under FP then CG (Table 5). For life span, life form and the low palatability plant functional groups, a similar trend of change in plant species diversity was also maintained in several cases (Table 6). Both diversity indices were lowest under the relatively lower rainfall season of 2007/08 (Fig. 13). The Shannon and Simpson reciprocal indices of diversity for the life span, life form and low palatability plant functional groups were greater under CG than RG (Table 6).

Table 5: Mean Simpson reciprocal and Shannon diversity indices over sites along grazing gradients for three consecutive seasons, assessed using quadrant and point intercept sampling methods

Sampling methods	Indices	Seasons	Grazing treatments [1]		
			Protected	Rotational	Continuous
Quadrat	Simpson reciprocal index of diversity (Richness)	2006/07	4.1 ± 0^{b}	3.4 ± 0^{c}	4.9 ± 0.1^{a}
		2007/08	2.9 ± 0^{b}	2.7 ± 0^{c}	4.4 ± 0.1^{a}
		2008/09	6.7 ± 0.1^{a}	4.9 ± 0.1^{b}	6.7 ± 0.1^{a}
	Shannon-Wiener diversity index	2006/07	1.93 ± 0.01^{b}	1.83 ± 0.02^{c}	2.32 ± 0.02^{a}
		2007/08	1.53 ± 0.02^{b}	1.28 ± 0.01^{c}	1.93 ± 0.02^{a}
		2008/09	2.50 ± 0.01^{b}	2.25 ± 0.02^{c}	2.55 ± 0.01^{a}
Point intercept	Simpson reciprocal index of diversity (Richness)	2006/07	11.8 ± 0.5^{b}	12.1 ± 0.6^{b}	16.1 ± 0.7^{a}
		2007/08	16.2 ± 0.6^{a}	6.6 ± 0.3^{c}	13.5 ± 0.5^{b}
		2008/09	24.1 ± 0.7^{a}	18.5 ± 0.7^{b}	18.6 ± 0.7^{b}
	Shannon-Wiener diversity index	2006/07	2.90 ± 0.03^{b}	2.94 ± 0.04^{b}	3.15 ± 0.03^{a}
		2007/08	3.23 ± 0.03^{a}	2.46 ± 0.04^{c}	3.05 ± 0.03^{b}
		2008/09	3.48 ± 0.02^{a}	3.30 ± 0.03^{b}	3.34 ± 0.02^{b}

[1] Different letters within same row indicate significant differences at $P<0.001$.

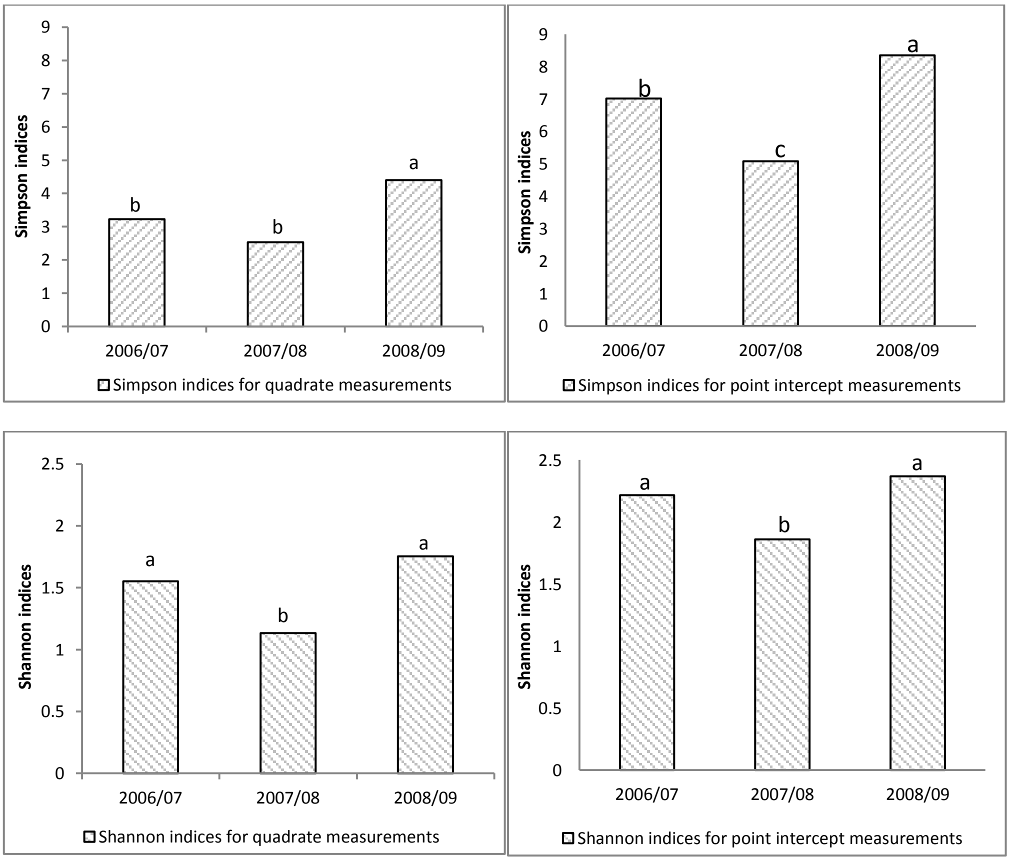

Figure 13: Shannon and Simpson reciprocal indices of plant species diversity over 10 sides in three consecutive seasons, different letters indicate significant differences.

Table 6: Shannon diversity indices along grazing gradients in10 rangeland sites in northern Syria assessed by quadrat and point intercept over three seasons

Sampling Method	Functional Group	2006/07			2007/08			2008/09		
		Closed	Managed	Open	Closed	Managed	Open	Closed	Managed	Open
Quadrat	**Life span**									
	Annual forb	1.85±0.02c	2.38±0.03b	2.57±0.02a	2.34±0.04a	1.15±0.05b	1.13±0.04b	2.66±0.01b	2.74±0.02a	2.72±0.02a
	Annual grass	1.47±0.03a	1.15±0.07b	0.96±0.05c	0.73±0.04a	0.94±0.11a	0.73±0.08a	1.08±0.03a	0.76±0.04b	0.75±0.03c
	Perennial forb	0.45±0.09b	0.74±0.05a	0.67±0.05a	0.79±0.13a	0.47±0.08b	0.42±0.07b	0.18±0.08c	0.64±0.03b	0.83±0.06a
	Perennial grass	0.69±0a	0.66±0b	0.63±0c	0.67±0a	0.69±0a	0.66±0a	0.69±0ab	0.69±0a	0.68±0b
	Shrub	1.43±0.06b	1.2±0.07c	1.8±0.07a	1.51±0.08b	1.51±0.13b	1.96±0.05a	1.25±0.06b	1.62±0.06a	1.6±0.07a
	Life form									
	Chamaephyte	1.07±0.07b	0.55±0.07c	1.39±0.06a	1.38±0.06b	1.11±0.12b	1.67±0.06a	1.04±0.1a	1.06±0.09a	1.18±0.07a
	Hemicryptophyte	0.47±0.01b	0.32±0.02c	0.79±0.02a	0.14±0.01b	0.17±0.01b	0.65±0.02a	0.73±0.01a	0.36±0.02b	0.73±0.02a
	Geophyte	0.11±0.01a	0.07±0.01b	0.09±0.01a	0.02±0.01b	0.03±0.01b	0.07±0.02a	0.11±0.01a	0.06±0.01b	0.12±0.01a
	Therophyte	2.11±0.02c	2.45±0.03b	2.63±0.02a	2.37±0.03a	1.25±0.05c	1.23±0.04a	2.83±0.01a	2.73±0.02b	2.74±0.02b
	Phanerophyte	0±0b	0.56±0.16a	0±0b	0.14±0.01b	0±0b	0.65±0.02a	0.73±0.01a	0±0b	0.73±0.02a
	Palatability									
	High	1.04±0.02c	1.2±0.02b	1.53±0.02a	0.45±0.02b	0.37±0.02c	0.69±0.03a	1.57±0.01a	1.27±0.02c	1.5±0.02b
	Medium	0.18±0.01a	0.03±0.01c	0.07±0.01b	0.14±0.01b	0.01±0.01c	0.37±0.02a	0.1±0.01b	0.13±0.01a	0.08±0.01b
	Low	1.81±0.03c	2.24±0.04b	2.48±0.03a	2.35±0.04a	1.22±0.06b	1.34±0.04b	2.76±0.02b	2.82±0.02a	2.71±0.02b
Point intercept	**Life span**									
	Annual forb	2.47±0.05b	2.46±0.06b	2.75±0.04a	2.91±0.04a	1.72±0.1c	2.41±0.06b	3.05±0.03a	2.99±0.03a	2.85±0.03b
	Annual grass	1.36±0.06a	0.84±0.1b	0.43±0.08c	0.64±0.08b	0.89±0.09a	0.17±0.09c	1.24±0.05a	0.41±0.07c	0.62±0.06b
	Perennial forb	0.66±0.11a	0.99±0.08b	0.75±0.09a	0.79±0.08b	1.16±0.11a	1.09±0.1a	0.37±0.1b	0.81±0.08a	1±0.06a
	Perennial grass	0.69±0a	0.69±0a	0.69±0a	0.64±0.02a	0.64±0.01a	0.53±0.03b	0.68±0.01a	0.68±0.01a	0.69±0a
	Shrub	1.44±0.06b	1.77±0.07a	1.92±0.06a	2.07±0.04a	1.55±0.08c	1.95±0.04b	1.8±0.05b	1.93±0.07b	2.16±0.04a
	Life form									
	Chamaephyte	1.29±0.05b	1.25±0.07b	1.58±0.05a	1.55±0.04a	1.26±0.07b	1.61±0.04a	1.23±0.06b	1.5±0.07a	1.81±0.03a
	Hemicryptophyte	0.95±0.06b	1.08±0.09b	1.6±0.07a	1.12±0.06b	0.53±0.06c	1.56±0.06a	1.52±0.05b	1.29±0.07c	1.66±0.05a
	Geophyte	0.34±0.04a	0.26±0.06ab	0.18±0.05b	0.37±0.05a	0.45±0.07a	0.43±0.11a	0.6±0.03b	0.46±0.07ab	0.74±0.05a
	Therophyte	2.62±0.04a	2.5±0.05ab	2.61±0.05a	2.84±0.04a	1.85±0.09c	2.39±0.06b	3.14±0.03a	2.87±0.03b	2.77±0.03c
	Phanerophyte	0.95±0.13b	0.45±0.14c	1.6±0.07a	0.97±0.05a	0.68±0b	1.56±0.06a	0±0c	0.41±0.16b	1.66±0.05a
	Palatability									
	High	2.04±0.03a	2.1±0.04a	1.94±0.04b	1.93±0.04a	1.49±0.06c	1.77±0.05b	2.29±0.02a	2.22±0.03a	2.02±0.03b
	Medium	0.03±0.02c	0.28±0.07b	0.58±0.06a	0.33±0.05a	0.17±0.06c	0.77±0.05a	0.73±0.06a	0.68±0.07a	0.73±0.07a
	Low	2.81±0.04a	2.81±0.06a	2.9±0.04a	3.01±0.03a	1.99±0.08c	2.63±0.04b	3.17±0.03a	2.99±0.04b	3.05±0.03b

Standard errors with values less than 0.01 are kept as zero. Different letters within rows of the same year indicates significant differences

3.3. Similarity indices

The average Morisita-Horn and Sørensen similarity indices for PI measurements were 0.97 and 0.86 respectively ranging from 0.95 to 0.99 for the former and from 0.84 to 0.88 for the latter. For the QD measurements, the averages were 0.75 and 0.69, whereas the ranges were from 0.70 to 0.82 and 0.67 to 0.71, respectively. Both indices are on a scale of 0 to 1, thus figures show a high level of similarity, hence low levels of corresponding dissimilarity (Table 7).

Table 7: Morisita-Horn abundance and Sørensen quantitative indices of similarity for grazing treatments based on quadrat and point intercept flora measurements

Similarity index	Data collection method	Grazing	Full protection	Rotational	Continuous
Morisita-Horn	Quadrat	Full protection	1	0.84	0.85
		Rotational		1	0.88
		Continuous			1
	Point intercept	Full protection	1	0.99	0.95
		Rotational		1	0.97
		Continuous			1
Sørensen	Quadrat	Full protection	1	0.67	0.71
		Rotational		1	0.68
		Continuous			1
	Point intercept	Full protection	1	0.82	0.70
		Rotational		1	0.74
		Continuous			1

3.4. Correlation of plant community parameters

Mean plant density and observed species richness over sites were positively and significantly ($P \leq 0.05$) correlated with 0.11 and 0.32 coefficients of determination for QD and PI measurements, respectively. However, the correlations between density and the three indices of diversity were insignificant with negligible coefficients of determination. Moreover, regardless of the measurement method used, the association between population density and richness for the individual grazing treatments followed a similar trend to that of the overall plots with a $P<0.1$ significant level and higher coefficients of determination. The significant level of interaction between plant density and the singleton index under full protection for the quadrate measurements was the only exception (Table 8).

Table 8: Coefficients of determination for plant density, species richness and indices of diversity in 10 rangeland sites with 3 grazing treatments in northern Syria

Grazing	Parameters	Plant density assessed by quadrat					Plant density assessed by point intercept				
		Density	Richness	Shannon	Simpson	Singletons	Density	Richness	Shannon	Simpson	Singletons
Overall	Density	**1**	**0.112*****	0.019	0.017	0.013	**1**	**0.319*****	0.002	0.000	0.001
(N=68)	Richness		**1**	**0.166*****	**0.124*****	0.043		**1**	**0.125*****	**0.093****	**0.177*****
	Shannon			**1**	**0.816*****	**0.066****			**1**	**0.806*****	**0.281*****
	Simpson				**1**	0.030				**1**	**0.095****
	Singletons					**1**					**1**
Protected	Density	**1**	**0.170***	0.112	0.138	**0.192****	**1**	**0.493*****	0.039	0.013	0.132
(N=22)	Richness		**1**	0.085	0.082	**0.179****		**1**	**0.194****	0.173	**0.548*****
	Shannon			**1**	**0.877*****	**0.210****			**1**	**0.833*****	**0.686*****
	Simpson				**1**	**0.188****				**1**	**0.367*****
	Singletons					**1**					**1**
Rotational	Density	**1**	**0.147***	0.001	0.000	0.006	**1**	**0.145***	0.038	0.013	0.031
(N=18)	Richness		**1**	0.033	0.005	0.078		**1**	0.068	0.035	0.063
	Shannon			**1**	**0.813*****	0.020			**1**	**0.744*****	0.055
	Simpson				**1**	0.019				**1**	0.016
	Singletons					**1**					**1**
Continuous	Density	**1**	**0.129***	0.041	0.020	0.008	**1**	**0.379*****	0.000	0.000	0.014
(N=28)	Richness		**1**	**0.371*****	**0.277*****	0.002		**1**	0.101	0.082	0.059
	Shannon			**1**	**0.779*****	**0.164****			**1**	**0.864*****	**0.399*****
	Simpson				**1**	0.051				**1**	**0.183****
	Singletons					**1**					**1**

Values in bold are different from 0 with a significance level of correlation at alpha=0.05; *=P<0.1; **=P<0.05, ***=P<0.01

4. Discussion

In general, the study area is characterized by high variability in physical and chemical soil characteristics. This is clearly shown in Table 2 in which the soils of Mahassa and Sheikh hilal were sandy with very low levels of potassium whereas the soils of the other sites were mostly silt loam. However, all of them were of high salinity, low organic matter, phosphorus and potassium.

Low fertility and high salinity are general characteristic of the Syrian arid rangeland soils (Jaubert et al., 1999). The precipitation is low and erratic and the dry period is long (Figs 2 and 3). The critical times for germination are December/January when precipitation is adequate and temperatures range from 5 to 15 °C, whereas for vegetative growth and flowering the critical period is February to May with a 10 to 30 °C temperature range. However, the minimum and maximum temperatures were very similar during the three years of the study (Fig. 2), but the rainfall distribution in the study area varied considerably during the study period for the two critical times mentioned above (Fig. 3). Absence of major fluctuations in the temperature regime, zero mineral fertilization and slow recycling due to extreme aridity and sheep as the dominant herbivore being constant in the study area, suggest that erratic precipitation and stocking rates are the governing factors of variability in plant density and diversity, whereas species richness was more site than grazing specific (Table 3). The background information in Table 1 may also shed some light on why richness was more affected by site characteristics than grazing. The 10 study sites cover a wide range of inherent anthropogenic range degradation factors such as levels of protection and duration of protection periods, cultivation, and proximity to main roads, residence areas and water points as well as uneven and spatial distribution of rainfall. These variations in site characteristics may explain the inconsistency in the direction of change in species richness and diversity along the grazing gradients for the individual and overall sites. The differences in inherent anthropogenic rangeland disturbances among the sites may have affected the differences in flora composition and its dynamics (Rusterholz et al., 2011; Morris et al., 2011). Stumpp et al. (2005) reported no significant correlations between distance from water source and vegetation parameters and concluded that neither levels of grazing nor nutrient gradients seem to exert any major influence on the vegetation composition of their study area. They added that precipitation appeared to be the overwhelmingly dominant factor. Vincke et al. (2010) found that floristic richness, density and regeneration showed an average increase with distance to bore hole, confirming the anthropogenic pressure on the woody plant population in their study area.

4.1. Plant density

A general trend of change in plant population density along the grazing gradient suggested that grazing practices consistently affected plant density in the study sites. Results showed year-by-site and site-by-grazing interaction for plant density which indicated site and year as overgrazing effects enhancement factors. Further analysis also showed positive, consistent and significant impacts of grazing on the population density of some functional groups such as perennial forbs. These results are in line with other research findings from the region and beyond (Louhaichi et al., 2012; Cesa & Paruelo, 2011; Kansur et al., 2008; Belgacem et al., 2008; Mosallam, 2007). The density of perennial forbs and associated chamaephytes changed in the opposite direction of the grazing gradient. The plant density of low and non-palatable geophytes and hemicryptophytes such as *Carex stenophylla* Wahlenb, *Poa bulbosa* L., *Allium* spp., and *Bellevalia macrobotrys* Boiss was more abundant under RG and FP than under CG. The bulbs and rhizomatic underground systems of this plant group makes them sensitive to high soil erosion rates associated with low green coverage under CG. Zobisch (1993) found that in the low range of average grass cover (i.e. below 40%) slight reductions in cover had major effects on soil loss. Moreover, the bulbs and rhizomes are major sources of food for rodent herbivores which are more abundant under full protection provided by the system. Heth & Nevo (1989) reported that out of 33 plant species hoarded by mole rats in the 21 studied nest mounds, 61% were geophytes, 21% perennial herbs, 15% annual herbs and 3% dwarf shrubs. In response to predation risk, squirrels forage food patches more thoroughly near cover than away from cover (Brown & Morgan, 2012). Higher population density for high persistent life form plant group under high grazing pressure has been reported through other range ecology investigations (Mosallam, 2007; Todd & Hoffman, 1999). These findings are in line with the dominance of geophytes under the rotational and fully protected areas in this study.

The significant interaction between site and grazing management indicated a change in ranking of the 10 sites along the grazing intensity gradient. However, in the majority of sites, plant density declined from FP to CG. In 1 out of the 10 sites, plant density was significantly higher under CG due to frequent opportunistic cultivation with barley leading to increase in weed population. In addition, the greater variance ratios and F-probabilities of grazing as main factor compared to the second level interaction suggests that its impact should not be ignored. The percent coefficient of variation for annual precipitation in the study area is above the 33% threshold determined in the disequilibrium theory for grazing disturbance to occur (Henrik et al., 2012). However, due to widespread bore wells and use of complementing feed in the Syrian steppe, water shortage is no longer a constraint for keeping livestock in the rangelands throughout the year. The conclusion from the above study was that rangelands with relatively stable rainfall patterns, and those with access to water or key resources, are potentially vulnerable to degradation. Grazing management in such areas should incorporate strategic rest periods. The change in ranking did not alter the fact that plant density in the protected areas was, regardless of the measurement method used, higher or not significantly different from the rotationally grazed and fully protected areas in 9 of the 10 sites surveyed (Figs 8 and 9).

The lack of significant differences in plant density between some grazing treatments (Table 4) could be attributed to differences in interplant competition levels within the grazing treatments. Frequent plant defoliation by herbivores reducing competition in the rotationally and continuously grazed areas as compared with those under full protection. High interplant competition for space, light, soil moisture and nutrients reduces the chances of survival for plants with less early vigor in the protected treatments. This might have resulted in few large-sized early vigorous plants per unit area under FP compared to more small sized ones under RG. Moreover, defoliation leads to easier distinction and counting of individual plants in the rotationally grazed areas. Tozer et al. (2008) reported that survival of *Vulpia* and barley grass and tiller production was generally greater in larger gaps, under continuous grazing.

The findings for plant density from this study are in line with other investigations on direct impacts of herbivory on above-ground vegetation cover along grazing gradients (Louhaichi et al., 2012; Cesa & Paruelo, 2011; Belgacem et al., 2008; Lodge et al., 2005). Some of the investigations emphasized the issue of selective grazing and differences in relative susceptibility among plant species with less capacity to recover from excessive defoliation and trampling as an important dimension of herbivory disturbance to plant community composition and species dynamics (El-keblawy et al., 2009; Gallacher & Hill, 2006). The issue of drought and patch over grazing as a cause for increasing herbivory disturbance in arid environments has also been investigated. Teague (2004) reported that periodic rests from defoliation known as rotational grazing have the potential to minimize the effects of patch overgrazing.

4.2. Plant community composition and species richness

The similarity in mean number of species for the two sampling methods suggested that the composition of the plant communities under the different grazing treatments did not change. Year seems to be the governing factor of variability in species richness, followed by site and then grazing (Fig. 13). What has been stated about the effects of environment and site in triggering year-by-site interaction for plant density might also apply to species richness (Table 3). Environmental conditions leading to an increase or decrease in plant density, such as drought, may also affect its composition (Fig. 13). The proportion of seed propagated in annual life cycle plants to perennial plants experiences significant shifts under dry and wet situations (Holzapfel et al., 2006).

There was an inconsistent direction of change in species richness along the grazing gradients among the 10 rangeland sites studied (Figs 10 and 11) as well as in different years of study (Fig. 13). The three sites for which species richness under continuous grazing was significantly below FP and RG were Adamia, Sheik hilal and Wadi Azeeb2. All three sites were strictly protected using fences and/or permanently guarded under short-term rangeland rehabilitation projects jointly implemented by ICARDA and the Syrian Steppe Directorate. Fluctuating levels of species richness between sites under a gradient of grazing pressure have been reported. Angassa & Oba (2010) reported that the herbaceous species richness declined with increasing age of the enclosure. As explained earlier for density, the lower species diversity under RG is probably due to greater population density of low palatability geophytes and hemicryptophyte life forms such as *Poa bulbosa* L., *Carex stenophylla* Wahlenb., and *Allium* spp. Proliferation of the above group of species may result from less bulb and rhizome exposure arising from lower soil erosion under RG than under CG and lower rodent population feeding on them than in FP areas. These are highly dominant species in the study area characterized by high population density and low diversity. In addition, most of the high potential parts of the study area were subjected to encroachment before the 1970 ban of cultivation law came into force. This also made their horizontal distribution quite patchy. They are highly adapted and resilient under the natural ecosystem conditions, but equally sensitive to anthropogenic disturbances such as cultivation and heavy traffic which are increasing in the arid Mediterranean steppes (Mundy & Musallam, 2003).

4.3. Plant species diversity

Trends in mean Shannon-Wiener, Simpson and Singleton indices of diversity, as shown by the results of different computations, did not strictly follow the grazing intensity gradient (Tables 3 and 5 and Fig. 13). The shift in high species diversity between FP and CG depending on data collection method is probably due to the relative differences in the weight of plant abundance and richness in the two methods. Plant abundance is more inflated in quadrat than point intercept measurements with higher sensitivity to rare species resulting from its greater space coverage. Under FP few competitive species dominates resulting in low proportional abundance and diversity whereas continuous defoliation under CG minimizes competition and maximizes chances for rare species to be represented. In the Mediterranean rangelands, the open patches generally have the greatest species richness, diversity and productivity (Yu et al., 2008). Results from a study by Todd & Hoffman (1999) showed no significant differences in diversity between heavily grazed communal land and a lightly grazed adjacent commercial farming site, either within individual plots or across all plots. The explanation given was rather similar to what we found in this study. The annuals which are dependent on seed for reproduction dominate the enclosure while the perennials and geophytes with alternative vegetative reproductive systems dominate the exclosure (Table 6). Noy-Meir and Kaplan (2002) reported a non-significant but consistent increase in cover of non-erect or twining species of small annual legumes with an increase in grazing intensity. Management for *in situ* conservation of the entire annual legume flora in productive Mediterranean vegetation requires, in different parts of the landscape, continuation of intense grazing and relative protection from grazing (Noy-Meir & Kaplan (2002). In our study, the highly palatable leguminous genus *Astragalus* is among the most common annual species under the three grazing treatments for both QD and PI measurements (Annexes A and B). It can be concluded that optimum richness and diversity that ensures basic plant community integrity is more important than maximum diversity.

4.4. Correlation of plant community parameters

The coefficients of correlation and determination between diversity indices and richness are consistently positive and higher than those with density. However, with high plant density of QD measurements under full protection, the coefficients of determination with diversity, particularly the singleton index become higher (Table 8). Plant density also explains the fact that the coefficients of determination between density and richness for the PI measurement are consistently higher than those of QD. Plant density is much lower with PI measurements compared to QD. This may make PI more suitable for arid rangeland of Nano-Phanerophytes and grass flora monitoring than QD. Inflating density in a patchy plant community such as the Mediterranean arid steppes (Nooralhamad, 2006) may favor some constituent species over others. The singleton index is particularly suitable for capturing rare species resurfacing under protection conditions (Neuteboom & Struik, 2005a).

The lack of significant correlation between the indices of diversity for the rotational grazing treatments may reflect the differences in the levels of sensitivity to dominance among them.

The trend of change in means of richness and diversity was the same, indicating that the impacts of grazing on plant density and on richness and species diversity in the study area are not heading in the same direction. However, the correlation test showed consistent and high coefficients of determination between richness and density. The most probable reasons for the mismatch in direction of change between density and richness while having a positive correlation could be the inconsistency in the direction of change in species richness along the grazing gradients across the study sites (Figs 11 and 12). This inconsistency could have resulted from the high and inherent temporal and spatial variations in the arid rangeland ecosystem components such as the anthropogenic factors (Table 1), environment (Figs 2 and 3) and soil (Table 2). The relatively short period of the rehabilitation program and then long-term use of sheep and goats as dominant herbivores before and during the recovery program and/or different combinations of those factors are other possible reasons. Morris et al. (2011) reported that land-use legacy of dry farming on vegetation remains nearly a century after cultivation has ceased. Kansur et al. (2008) found that grazing patterns under 23-year protection and grazing areas were similar and concluded that relatively stable assemblages of species were probably derived from high grazing pressure experienced before exclosure establishment. Snyman & Preez (2005) found that rainfall and nitrogen, not grazing intensity, were the limiting environmental factors of the semiarid central rangelands of South Africa. Sheep and goat rearing in the Fertile Crescent dates back to the Neolithic revolution (Sanlaville in: Mundy & Musallam, 2003). The factors listed or different combinations may have shaped the plant community in such a way that it could not have been fixed through grazing that does not involve a significant change in the dominant herbivore types. The inconsistency in direction of species richness and diversity found in this study showed a lack of structural changes in plant community composition along the grazing gradient investigated. These findings are in line with the above-mentioned conclusions that centuries of herbivory impacts on plant community composition can probably not be changed by a slight and irregular reduction in stocking rates for a few decades. The rehabilitation package introduced may just have helped to improve the plant density under protection and rotational compared to continuous grazing, but maintained the community composition and diversity as they were with some shift in proportional abundance.

The correlation between richness and diversity was more consistent than the correlation between richness and density. This clearly reflects the fact that the richness component outweighs that of density in the computation of the indices of diversity used (Magurran, 1988). However, under high plant abundance, the correlation of richness with density becomes stronger compared to diversity. The reason for this could be the fact that high plant density, particularly in spatially heterogeneous Mediterranean arid plant communities (Kansur et al., 2010), is usually associated with the dominance of one or several species limiting the effect of the richness component in the diversity computation.

The significantly higher level of abundance for the low palatability geophytes and perennial grasses within the rotationally grazed areas (Table 5) was probably the reason for the lower diversity under rotational grazing than in the fully protected or continuously grazed areas. Patches of the highly persistent perennials namely *Carex stenophylla* Wahlenb and *Poa bulbosa* L. covered a large part of the surveyed areas sparsely populated with Nano-phanerophytes such as *Noa mucronata* (Forssk.) Asch. & Schweinf, which make the plant density of perennials significantly higher than the annuals (Figs 6 and 10). These large patches resulted in species distribution within the plant communities skewed towards dominance of the above few species and, hence low diversity (Figs 11 and 12). Low palatability species are known to be less competitive as compared to highly palatable ones for which ramification and re-growth is stimulated by defoliation and trampling (Clauss et al., 2010; Noy-Meir & Kaplan, 2002). However, the low grazing compatibility of geophytes is compensated for by their high persistence arising from their multi-reproductive systems of bulbs, rhizomes and seeds. These mechanisms help them overcome the harsh abiotic stresses of the arid Mediterranean rangelands.

In summary, the low coefficients of determination between plant density and of richness and diversity reflects the fact that linearity between the effects of disturbance and the changes in plant community composition is not, to say the least, consistent (SRM, 1995).

4.5. Indices of similarity for grazing treatments

The high levels of Morisita-Horn and Sørensen similarity indices suggested that the species richness of the plant communities under the three grazing treatments was not different from each other. For plant communities with a similar number of species or (richness), similarity indices will be, regardless of plant density, close to their maximum levels of (1). Pitman et al. (2005) stated that the Sørensen index is not independent of diversity; only compositionally identical samples of the same diversity can attain its maximum (1). Under the different grazing treatments, the difference in total number of species (richness) captured by the two sampling methods was not consistently different (Tables 3 and 4).

Conclusions

- The significant increase in overall plant density along the grazing gradient from the CG to FP found in most sites covered in this study reflect the positive impacts of resting and rotational grazing on above ground vegetation of arid Mediterranean rangelands.

- The higher plant density of perennial grasses and lower diversity in overall plant species under rotational grazing is attributable to change in plant community composition resulting from increase in plant species with lower proportional abundance. This implies that rotational grazing promotes perennial grasses by probably maintaining greater soil integrity and better green cover due to less trampling during the long dry summer and discontinuation of green cover depletion at seed setting.
- The simultaneous decline of perennial grass density and increase in annuals under continuous grazing is attributable to the long term combined effects of seasonal and spatial rainfall distribution and overstocking at critical periods for soil integrity and flora renewal dynamics.
- Rotational and continuous grazing seemed to shape-up plant community composition of arid Mediterranean rangelands towards opposite directions. While perennial grasses proliferate under the former, annuals increase under the latter. The rehabilitation program seemed to have shaped-up the plant species composition under rotational grazing by promoting the perennial grasses constituting the main elements of integrity for arid range plant communities. The results imply that incorporation of inter-seasonal grazing and herbivore variation into the current rangeland rehabilitation program could improve the outcome and bring greater sustainability into it.

Annexes

Annex A: Relative frequencies and density of most common species (relative frequency ≥1%) by quadrat

Functional group	Species	% Frequency	%Relative frequency	%Density	Relative density
Annual forb (33 species)	Salsola volkensii Schweinf. & Asch.	85.3	6.9	117.0	11.0
	Astragalus spp.	64.7	5.2	28.3	2.7
	Plantago ovata Forssk.	64.7	5.2	58.5	5.5
	Bupleurum semicompositum L.	57.4	4.6	26.9	2.5
	Malva aegyptia L.	57.4	4.6	32.6	3.1
	Erodium acaule (L.) Becherer & Thell.	51.5	4.2	59.3	5.6
	Filago desertorum Pomel	51.5	4.2	29.2	2.7
	Herniaria hemistemon J.Gay	51.5	4.2	29.8	2.8
	Leptaleum filifolium (Willd.) DC.	42.6	3.5	19.1	1.8
	Helianthemum ledifolium (L.) Mill.	41.2	3.3	28.6	2.7
	Koelpinia linearis Pall.	41.2	3.3	5.2	0.5
	Torularia torulosa (Desf.) Hedge & J. Leonard	36.8	3.0	6.0	0.6
	Adonis dentata Delile	33.8	2.7	21.0	2.0
	Astragalus asterias Hohen	33.8	2.7	7.4	0.7
	Girgensohnia oppositifolia	27.9	2.3	25.3	2.4
	Ziziphora tenuior L.	27.9	2.3	9.4	0.9
	Androsace maxima L.	26.5	2.1	76.8	7.2
	Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.	26.5	2.1	17.0	1.6
	Scabiosa aucheri Boiss.	26.5	2.1	3.8	0.4
	Gypsophila viscosa Murray	22.1	1.8	12.0	1.1
	Teucrium parviflorum L.	22.1	1.8	83.1	7.8
	Onobrychis spp.	20.6	1.7	3.0	0.3
	Arnebia tinctoria Forssk.	19.1	1.5	2.7	0.3
	Erodium glaucophyllum (L.) L'Her.	17.6	1.4	17.1	1.6
	Euphorbia spp.	17.6	1.4	13.2	1.2
	Crucianella ciliata Lam.	16.2	1.3	4.5	0.4
	Senecio spp.	16.2	1.3	5.0	0.5
	Nigella arvensis L.	14.7	1.2	6.8	0.6
	Roemeria hybrida (L.) DC.	14.7	1.2	14.1	1.3
	Silene coniflora Otth	14.7	1.2	3.6	0.3
	Lasiopogon muscoides (Desf.) DC.	13.2	1.1	11.6	1.1
	Papaver syriacum Boiss. & Blanche	13.2	1.1	3.8	0.4
	Malva rotundifolia Desf.	11.8	1.0	10.9	1.0
Annual grass (9 species)	Schismus spp.	82.4	29.5	59.7	34.3
	Koeleria phleoides (Vill.) Pers.	61.8	22.1	17.7	10.2
	Hordeum glaucum Steud.	35.3	12.6	3.9	2.3
	Ceratocephalus falcatus (L.) Pers.	26.5	9.5	8.3	4.8
	Bromus tectorum L.	25.0	8.9	39.0	22.4
	Bromus danthoniae Trin.	17.6	6.3	7.3	4.2
	Lolium temulentum L.	14.7	5.3	3.9	2.2
	Aegilops crassa (Zhuk.) Chennav	11.8	4.2	29.4	16.9
	Schismus arabicus Nees	4.4	1.6	4.7	2.7
Perennial forb (9 species)	Allium spp.	63.2	51.8	9.3	12.1
	Achillea fragrantissima (Forssk.) Sch.Bip.	23.5	19.3	52.7	68.8
	Andrachne telephioides L.	11.8	9.6	1.8	2.3
	Bellevalia macrobotrys Boiss.	7.4	6.0	5.6	7.3
	Allium rothii Zucc.	5.9	4.8	1.3	1.6
	Pancratium Sickenbergeri Aschers. & Schweinf. ex C. & W. Bar	5.9	4.8	2.0	2.6
	Achillea aleppica DC.	1.5	1.2	1.0	1.3
	Allium aschersonianum Barbey	1.5	1.2	1.0	1.3
	Muscari commutatum Guss.	1.5	1.2	2.0	2.6
Perennial grass (2 species)	Poa bulbosa L.	83.8	58.2	475.1	38.2
	Carex stenophylla Wahlenb	60.3	41.8	768.1	61.8
Shrub (15 species)	Noaea mucronata (Forssk.) Asch. & Schweinf.	51.5	17.0	5.5	5.1
	Salsola vermiculata L.	48.5	16.0	22.6	21.3
	Leontodon arabicum Boiss.	39.7	13.1	13.3	12.5
	Artemisia herba-alba	32.4	10.7	11.1	10.5
	Haloxylon articulatum Pomel	29.4	9.7	7.9	7.4
	Peganum harmala L.	23.5	7.8	2.8	2.6
	Verbascum damascenum Boiss.	14.7	4.9	3.0	2.8
	Atriplex leucoclada Boiss.	11.8	3.9	10.8	10.1
	Haplophyllum longifolium Boiss.	10.3	3.4	2.7	2.6
	Onopordum anisacanthum Boiss.	10.3	3.4	4.4	4.2
	Salsola spinosa Lam.	8.8	2.9	3.2	3.0
	Anabasis syriaca Iljin	5.9	1.9	3.8	3.5
	Atriplex canescens (Pursh) Nutt.	5.9	1.9	8.5	8.0
	Marrubium vulgare vulgare L.	4.4	1.5	2.7	2.5
	Atriplex halimus L.	2.9	1.0	2.0	1.9

Annex B: Relative frequencies and density of the most common species with relative frequency ≥1% recorded by point intercept and sorted according to functional groups

Functional group	Species	% frequency	%Relative frequency	% density	Relative density
Annual forb (27 species)	Salsola volkensii Schweinf. & Asch.	85.3	8.5	16.4	5.0
	Plantago ovata Forssk.	60.3	6.0	10.6	3.2
	Erodium acaule (L.) Becherer & Thell.	58.8	5.9	10.5	3.2
	Astragalus spp.	57.4	5.7	7.4	2.2
	Malva aegyptia L.	54.4	5.4	10.0	3.0
	Filago desertorum Pomel	51.5	5.1	6.0	1.8
	Herniaria hemistemon J.Gay	48.5	4.8	6.7	2.0
	Bupleurum semicompositum L.	47.1	4.7	5.8	1.7
	Girgensohnia oppositifolia	32.4	3.2	6.4	1.9
	Helianthemum ledifolium (L.) Mill.	30.9	3.1	8.5	2.6
	Koelpinia linearis Pall.	30.9	3.1	2.7	0.8
	Anthemis palestina Boiss.	29.4	2.9	5.4	1.6
	Adonis dentata Delile	26.5	2.6	9.8	3.0
	Scabiosa aucheri Boiss.	26.5	2.6	4.3	1.3
	Torularia torulosa (Desf.) Hedge & J. Leonard	26.5	2.6	6.0	1.8
	Androsace maxima L.	23.5	2.3	9.8	3.0
	Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.	22.1	2.2	6.7	2.0
	Arnebia tinctoria Forssk.	20.6	2.0	4.4	1.3
	Malva rotundifolia Desf.	20.6	2.0	9.0	2.7
	Leptaleum filifolium (Willd.) DC.	19.1	1.9	10.8	3.3
	Teucrium parviflorum L.	19.1	1.9	15.4	4.7
	Erodium glaucophyllum (L.) L'Her.	16.2	1.6	7.5	2.3
	Onobrychis spp.	16.2	1.6	1.1	0.3
	Papaver syriacum Boiss. & Blanche	14.7	1.5	1.9	0.6
	Ziziphora tenuior L.	14.7	1.5	3.4	1.0
	Silene coniflora Otth	11.8	1.2	1.5	0.5
	Centaurea spp.	10.3	1.0	3.9	1.2
Annual grass (7 species)	Schismus spp.	80.9	46.2	18.7	38.0
	Koeleria phleoides (Vill.) Pers.	36.8	21.0	5.7	11.5
	Hordeum glaucum Steud.	23.5	13.4	4.2	8.5
	Bromus tectorum L.	19.1	10.9	9.8	19.9
	Bromus danthoniae Trin.	5.9	3.4	7.5	15.3
	Ceratocephalus falcatus (L.) Pers.	4.4	2.5	1.3	2.7
	Lolium temulentum L.	4.4	2.5	2.0	4.1
Perennial forb (7 species)	Allium spp.	52.9	42.4	5.5	17.0
	Achillea fragrantissima (Forssk.) Sch.Bip.	29.4	23.5	13.1	40.3
	Andrachne telephioides L.	25.0	20.0	2.4	7.2
	Bellevalia macrobotrys Boiss.	11.8	9.4	1.5	4.6
	Achillea aleppica DC.	1.5	1.2	6.0	18.5
	Allium aschersonianum Barbey	1.5	1.2	1.0	3.1
	Asphodelus microcarpus Salzm. & Viv.	1.5	1.2	1.0	3.1
	Ixiolirion tataricum (Pall.) Herbert	1.5	1.2	2.0	6.2
Perennial grass (2 species)	Poa bulbosa L.	83.8	58.8	28.6	48.5
	Carex stenophylla Wahlenb	58.8	41.2	30.4	51.5
Shrub (16 species)	Salsola vermiculata L.	66.2	16.3	11.8	8.8
	Noaea mucronata (Forssk.) Asch. & Schweinf.	58.8	14.5	9.8	7.3
	Artemisia herba-alba	51.5	12.7	17.9	13.4
	Haloxylon articulatum Pomel	45.6	11.2	12.2	9.1
	Peganum harmala L.	35.3	8.7	6.5	4.9
	Leontodon arabicum Boiss.	23.5	5.8	5.2	3.9
	Atriplex halimus L.	20.6	5.1	2.6	2.0
	Haplophyllum longifolium Boiss.	19.1	4.7	1.5	1.1
	Verbascum damascenum Boiss.	16.2	4.0	3.0	2.2
	Atriplex leucoclada Boiss.	14.7	3.6	9.1	6.8
	Atriplex canescens (Pursh) Nutt.	11.8	2.9	10.8	8.0
	Salsola spinosa Lam.	11.8	2.9	3.6	2.7
	Anabasis syriaca Iljin	5.9	1.4	8.8	6.5
	Onopordum anisacanthum Boiss.	5.9	1.4	8.8	6.5
	Alhagi graecorum Boiss.	4.4	1.1	3.3	2.5
	Marrubium vulgare vulgare L.	4.4	1.1	1.3	1.0

Annex C: List of families, genera and species of plant recorded in the 10 study sites in northern Syria

Families	**Species**
Aizoaceae	Aizoon hispanicum L.
Amaryllidaceae	Ixiolirion tataricum (Pall.) Herbert
Apiaceae	Bupleurum semicompositum L.
	Coriandrums ativum L.
Asteraceae	Achillea aleppica DC.
	Achillea fragrantissima (Forssk.) Sch.Bip.
	Artemisia herba-alba Asso.
	Matricaria aurea (Loefl.) Sch.Bip.
	Onopordum anisacanthum Boiss.
	Picris radicata (Forssk.) Less.
Boraginaceae	Arnebia tinctoria Forssk.
	Heliotropium europaeum L.
	Moltkia caerulea Lehm.
Brassicaceae	Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.
	Leptaleum filifolium (Willd.) DC.
Capparaceae	Capparis spinosa L.
Caryophyllaceae	Gypsophila viscosa Murray
	Herniaria hemistemon J.Gay
	Holosteum spp.
	Holosteum umbellatum L.
	Silene coniflora Otth
	Spergularia diandra (Guss.) Boiss.
	Teucrium parviflorum L.
	Vaccaria pyramidata Medik.
Chenopodiaceae	Anabasis syriaca Iljin
	Atriplex canescens (Pursh) Nutt.
	Atriplex halimus L.
	Atriplex leucoclada Boiss.
	Atriplex polycarpa (Torr.) S. Watson
	Girgensohnia oppositifolia (Pall.) Fenzl
	Haloxylon articulatum Pomel
	Noa mucronata (Forssk.) Asch. & Schweinf.
	Salsola spinosa Lam.
	Salsola vermiculata L.
	Salsola volkensii Asch. & Schweinf.
Compositeae	Anthemis palestina Boiss.
	Carthamus syriacus Boiss.
	Centaurea ammocyanus Boiss.
	Centaurea spp.
	Filago desertorum Pomel
	Filago vulgaris Lam.
	Gymnarrhena micrantha Desf.
	Koelpinia linearis Pall.
	Lactuca serriola L.
	Lasiopogon muscoides (Desf.) DC.
	Leontodon arabicum Boiss.
	Senecio desfontainei Druce
	Senecio spp.
	Silybum spp.
	Sonchus oleraceus L.
	Xanthium strumarium L.
Convolvolaceae	Convolvulus betonicifolius Mill.
Crucifereae	Brassica spp.
	Cardaria draba (L.) Desv.
	Eruca sativa Mill.
	Malcolmia crenulata (DC.) Boiss.
	Sinapis arvensis L.
	Sisymbrium bilobum (K.Koch) Grossh.
	Sisymbrium spp.
	Torularia torulosa (Desf.) Hedge & J. Leonard
Cyperaceae	Carex stenophylla Wahlenb

Families	**Species**
Dipsaceae	Scabiosa aucheri Boiss.
Euphorbiaceae	Andrachne telephioides L.
	Chrozophora tinctoria (L.) Raf.
	Euphorbia spp.
Fabaceae	Alhagi graecorum Boiss.
	Medicago spp.
	Onobrychis spp.
Geraniaceae	Erodium acaule (L.) Becherer & Thell.
	Erodium cicutarium (L.) L'Her.
	Erodium glaucophyllum (L.) L'Her.
Gramineae	Aegilops crassa (Zhuk.) Chennav
	Bromus danthoniae Trin.
	Bromus tectorum L.
	Hordeum glaucum Steud.
	Koeleria phleoides (Vill.) Pers.
	Lolium temulentum L.
	Poa bulbosa L.
	Schismus arabicus Nees
	Schismus spp.
Labiateae	Salvia spinosa L.
Lamiaceae	Marrubium vulgare L.
	Ziziphora tenuior L.
Liliaceae	Allium spp.
	Allium aschersonianum Barbey
	Allium rothii Zucc.
	Asphodelus microcarpus Salzm. &Viv.
	Bellevalia macrobotrys Boiss.
	Gagea spp.
	Muscari commutatum Guss.
	Pancratium sickenbergeri Aschers. &Schweinf. ex C. & W. Bar
Malvaceae	Malva aegyptia L.
	Malva rotundifolia Desf.
Papaveraceae	Papaver syriacum Boiss. & Blanche
	Roemeria hybrida (L.) DC.
Papilionaceae	Astragalus asterias Hohen
	Astragalus hamosus L.
	Astragalus spinosusspinosus (Forssk.) Muschl.
	Astragalus spp.
	Hippocrepis unisiliquosa L.
	Lathyrus spp.
	Trigonella aleppica Del.
	Trigonella radiata (L.) Boiss.
	Vicia lutea L.
Plantaginaceae	Plantago coronopus L.
	Plantago lanceolata L.
	Plantago ovata Forssk.
Primulaceae	Androsace maxima L.
Ranunculaceae	Adonis dentate Delile
	Cerato cephalusfalcatus (L.) Pers.
	Nigella arvensis L.
Resedaceae	Reseda luteola L.
Rubiaceae	Crucianella ciliata Lam.
Rutaceae	Haplophyllum longifolium Boiss.
Scrophulariaceae	Linaria chalepensis (L.) Mill.
	Linaria joppensis Bornm.
	Verbascum damascenum Boiss.
Sistaceae	Helianthemum ledifolium (L.) Mill.
Umbellifereae	Torilisl eptophylla (L.) Rchb.f.
Zygophyllaceae	Fagonia bruguieri DC.
	Peganum harmala L.

Chapter 3

Impact of Grazing on Soil Seed Bank Replenishment under the Mediterranean Climate of Northern Syria

This chapter has been submitted to *The Journal of Arid Environments* as:

Impact of grazing on soil seed bank replenishment under the Mediterranean climate of Northern Syria

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Chapter 3. Impact of Grazing on Soil Seed Bank Replenishment under the Mediterranean Climate of Northern Syria

Abstract

This study was carried out on 10 sites in Syria during the autumn of 2006 and 2007 to assess grazing impacts on soil seed bank (SSB) composition in arid Mediterranean rangelands under rehabilitation. Nine soil cores of 20 cm diameter and 5 cm depth were collected along grazing gradients in each site. The SSB composition was analyzed using SSB tests on 2 and 3 sub-samples of 0.25 and 3 kg soil, respectively.

The significant grazing-by-site interaction for both physical and germinable SSB size suggests that impact of grazing on soil seed bank size is site specific and environment moderated. The results showed that for all sites near people and animal agglomerations, SSB size was higher under continuous grazing in which ephemerons and non-palatable plants with limited constraints for seed setting dominate.

For the functional groups, the results showed a simultaneous decline and surge in physical and germinable soil seed bank sizes of annuals and those of perennials under the same grazing treatments. This suggests relative differences in root competition and gap exploitation efficiency among the plant functional groups recorded and calls for a better grazing management to maintain greater plant community integrity.

As shown in the above ground vegetation studies, lower effective number of species and Shannon-Wiener diversity indices for physical and germinable soil seed banks were also recorded under rotational grazing (RG) compared to full protection and continuous grazing indicating a shift in plant community composition under rotational grazing towards perennial grasses (PG) with low proportional abundance.

PG with no physical SSB record generated 208 seedlings m^{-2} under continuous grazing. This is probably due to seed setting failure resulting from overgrazing covered by vegetative reproduction. The widely used phanerophytes in the rangeland rehabilitation program had a physical soil seed bank size of 59.7 to 119 seed m^{-2} and a zero germinable one. This shows high complementarity between physical and germinable seed testing methods for rangeland monitoring.

Morisita-Horn and Sørensen similarities were higher for vegetation measurements with GSSB than for those with PSSB.

Inter-season rotational grazing could minimize the combined effects of arid-ecosystem variability and grazing on plant community, herbivore variation could maintain interdependent plant functional group balance and GSSB test could bring efficiency and effectiveness in planning and monitoring arid rangeland rehabilitation.

Keywords: seed bank, rangelands, richness, diversity, grazing, Syria

1. Introduction

The soil seed bank is a major component of self-regeneration mechanisms in most floral systems, thus its understanding is crucial for vegetation dynamics and management methods. Because of its significance it has been a major topic of research in general plant ecology (Csontos, 2007; Benoit et al., 1989; Hayashi & Numata, 1971), weed ecology (Concenço et al., 2011; Tozer et al., 2010), forestry (Leonel & Miguel, 2011; Wang et al., 2009) and in pasture and grassland ecological studies (Harel et al., 2011; Gutiérrez & Meserve, 2003; Russi & Cocks, 1992).

A soil seed bank is the stock of mature, viable seeds present at soil surface or buried in the soil and litter at a determinate time and place (Qiuyan et al., 2011; Csontos, 2007; Martins & Engel, 2007). Namuta et al. (1964) described buried seed population in the soil as the mother's womb of plant communities. The soil seed bank is the resting place of seeds and forms an important component of the seed propagated plant life cycles (Gulden & Shirtliffe, 2009).

Overgrazing refers to a mismatch between herbivore type, stocking rate, timing and continuity of access with the range carrying capacity. Overgrazing is considered a major cause of anthropogenic disturbance in arid rangeland of the Mediterranean region and beyond (Gamoun et al., 2011; Harel et al., 2011; Boyd & Svejcar, 2009; Le Houerou, 1981) and affects the seed bank and its relationships with the aboveground vegetation (Tessema et al., 2012; Li, 2008). Because of the widespread of bore wells and water points, lack of snow coverage during winter, use of barley from opportunistic cultivation and alternative feed sources, it is possible to permanently maintain livestock in the Syrian arid rangelands, thus disabling the extreme aridity based protection from degradation advocated by the disequilibrium theory (Henrik et al., 2012).

Soil seed banks along a grazing gradient of arid rangeland sites have been investigated with results differing from one habitat to another. Kassahun et al. (2009) did not find strong evidence that severely degraded rangelands maintain adequate soil seed banks that would improve the condition of it through restoration. Ma et al. (2010) found a significant increase in the density of buried seeds with increasing disturbance and concluded that restoration of disturbed areas is not limited by seed sources.

For annual and some perennial plant species for which reproduction is only by seed, the sole source of future plant populations and temporal dispersal is the soil seed bank (Gulden & Shirtliffe, 2009; Nicol et al., 2007). Seed banks can be regarded merely as one of several alternative means of persistence, dispersal in time rather than in space and a reserve of genetic material (Fenner, 2008). Research in weed and forest ecology showed that soil seed bank size, composition, diversity and persistence play a crucial role in flora dynamics of crop and pasture lands and forest ecosystems (Fang & Cai, 2011; Wang et al., 2009).

In the arid Mediterranean rangelands under rehabilitation, studies on soil seed bank replenishment along grazing gradients are rare. More emphasis has been devoted to vegetation cover and not clearly linked to rehabilitation processes (Louhaichi et al., 2012; El-keblawy et al., 2009; Gallacher & Hill, 2006; Holzapfel et al., 2006; Nooralhamad, 2006; Noy-Meir & Kaplan, 2002; El-Barasi, 2005; Peco et al., 1998).

In Syria, semi-arid and arid rangeland represents 55% of the total land area and it is a major source of free feed for 15 million head of sheep. A large-scale rehabilitation program covering more than 100,000 ha has been implemented over the past five decades (Sanlaville, 2003; Mourad, 2000; Jaubert et al., 1999). The impact of the extensive rehabilitation programs on the soil seed bank size and composition and implications for rangeland recovery has not been comprehensively investigated.

Arid rangeland rehabilitation programs are based on assumptions that resting, shrub transplanting followed by rotational grazing help replenish soil seed bank size, richness and diversity. This study aimed at testing the above assumption by investigating the effects of resting, rotational and continuous grazing on soil seed bank size, species richness and diversity and implications for vegetation cover in the arid Mediterranean rangelands of Syria.

2. Material and methods

2.1. Study sites

The study was carried out in the Syrian arid steppe of Aleppo, Hama and Homs provinces with less than 200 mm mean annual rainfall. The means of annual precipitation during the 3 consecutive seasons in the study area were 124, 90 and 129 mm. The study sites are located between latitudes: 37°.144E - 37°.850E and the longitudes: 34°.129N - 35°.656N. They consist of 10 range reserves established and managed by the Syrian Steppe Directorate using transplanting of halophyte shrubs and rotational grazing. Fully protected areas are kept within some of the range reserves for range status monitoring purposes.

2.2. Experimental set-up

The study covered 10 range reserves of which 8 had full protection (FP), 6 had rotational grazing (RG) and 10 had continuous grazing (CG) treatments. The study was carried out in two consecutive seasons namely 2006/07 and 2007/08. During each season, soil sampling and testing was carried out on 3 ha each of the 24 grazing treatments (macro plot) within the 10 range reserves (Table 1).

2.3. Soil seed bank sampling

From each grazing treatment, a total of nine soil cores of 20 cm in diameter and 5 cm of depth were collected (Csontos, 2007; Hayashi & Numata, 1971). The nine soil cores of 20 cm in diameter, all taken from each treatment in this study, are equivalent to a total of 90 soil cores of 2 cm each. A 20 cm in diameter sampling device was found more suitable for plots with high stone and gravel contents in the study areas.

Table 1: Range sites, characteristics, anthropogenic factors and grazing treatments within the study area

Provinces	Sites	Years of protection	Shrub planting	Anthropogenic factors[1]	Grazing treatments[2]
Aleppo	Obeisan	0	No	1, 4	Continuous
		20	Yes	1, 4	Protected
		20	Yes	1, 4	Rotational
	Adamia	0	No	1, 2	Continuous
		10	Yes	1, 2	Protected
		10	Yes	1, 2	Rotational
	Hammam	0	No	1, 2	Continuous
		5	No	1, 2	Protected
		5	No	1, 2	Rotational
	Wadi Azeeb1	0	No	1, 2, 3	Continuous
		40	Yes	1, 2, 3	Protected
		40	Yes	1, 2, 3	Rotational
	Wadi Azeeb2	0	No	2	Continuous
		5	Yes	2	Protected
	Maragha	0	No	1, 2	Continuous
		20	Yes	1, 2	Rotational
	Mshairifeh	0	No	1, 4	Continuous
		20	Yes	1	Rotational
Hama	Ithria	0	No	1, 2, 3	Continuous
		40	Yes	1, 2, 3	Protected
	Sheik hilal	0	No	1, 2	Continuous
		5	Yes	1, 2	Protected
Homs	Mahassa	0	No	2	Continuous
		5	Yes	2	Protected

[1]: Numbers represent anthropogenic factors as follows: 1 = near people and animal agglomerations; 2 = near main road; 3 = near water point; 4 = cultivation; [2]: 0.03 m^3 of soil from 9 cores of 20 cm diameter and 10 cm depth on three transects of 100 m long, each were collected annually from every grazing treatment

There was some overlapping in the sampling positions within the macro-plots in the two seasons of the study. The nine soil cores were collected on three transects of 100 m each in length. The three transects were in the form of a radius starting from the central points of each macro-plot to opposite directions making approximate angles of 120 degrees between them. On each of the three radii, three soil cores were collected at approximately 25 m intervals. The process was repeated in the second season with the locations of transects shifted. The volume of each soil core was $10^2 \times 5 \times 3.14 = 1570\ cm^3$. Hayashi & Numata (1964) found that 500-600 cm^3 of soil was the minimum soil sample size to reach the asymptote of the seed/soil line graph of the grassland soil seed bank studied. The total weight of soil from each site ranged between 11 and 20 kg depending on the physical soil characteristics and gravel content. Late autumn sampling for detecting the entire soil seed bank (Csontos, 2007) was adopted for this study which corresponds to the second and first halves of September and October in the Syrian Steppe (Russi & Cocks, 1992).

Three composite samples were prepared from the nine soil cores by mixing three randomly selected cores and removing debris, stones and gravels after separating seeds and fruits structures from them (Bakker et al., 1996).

2.4. Soil seed bank testing

2.4.1. Physical seed extraction

From the composite soil samples representing grazing treatments, two sub-samples of 0.25 kg each were used for physical seed extractions. Physical seed extraction was done by soaking the 0.25 kg of debris free soil samples in tap water for 5 min, followed by stirring and filtering with a 200 µm screen, spreading over Whatman filter paper and placing in an oven with air circulation at 50±5 °C for 2 h. Then the samples were sorted by hand-held pointed tweezers under a binocular microscopic with ×100 magnifications (Russi & Cocks, 1992).

Seed identification was done by comparing the physically extracted seeds with seeds collected from the standing plants in the protected study areas and in the growing out test plants and by conducting separate growing-out tests for verification of plant species identity under the same greenhouse conditions.

As stated, the observations on physical soil seed bank (PSSB) were made on two sub-samples of 0.25 kg each. In order to have sizable species richness and abundance to optimize the validity of the diversity indices, the observations from the two sub-samples were pooled. Pooling of the observations from the grazing treatments within each range site and within each season resulted in 16, 12 and 20 observations of PSSB size, richness and indices of diversity from the FP, RG and CG treatments, respectively. However, the original number of samples collected from the FP, RG and CG areas within the study sites were 144, 108 and 180 soil cores, respectively. The figures are products of multiplying two seasons by nine soil cores per treatment by eight RG, six FP and ten CG treatments, respectively.

The species frequency (in %) was calculated based on the frequency of a species occurrence in the total number of observation units divided by the total number of samples and multiplied by 100. Relative density (seed bank size) refers to the mean number of seeds for each species recorded under each grazing treatment divided by the total number of individual seeds in that treatment and multiplied by 100.

The total number of seeds recorded from the two and three sub-samples of 0.25 kg and 3 kg soil used for PSSB and GSSB tests were converted into seed m^{-2} by multiplying by the number of seeds and seedlings found in each of them by 3.3 and 59.4 respectively. The figures 3.3 and 59.4 are calculated by converting the 2080 cm^3 volume of the soil put in the three trays of the GSSB test into m^2.

2.4.2. Germinable soil seed bank assessment

From each of the three composite samples representing grazing treatments, three sub-samples of 3.0 kg each were used for germinable soil seed bank test. The tests were carried out in a greenhouse set at 20±5 °C, 16/8 h light regime and a relative humidity of 60% at the ICARDA main research station, Syria. The tests were conducted using 13 cm deep, 26 cm wide and 40 cm long plastic trays with drainage holes at the bottom. The trays were filled up with about 8 cm thick layers of river sand sterilized using an oven set at 100 °C for 3 h. The 3 kg of test soil prepared as mentioned above was evenly spread at about 2 cm thick layer over the 8 cm sterilized sand layer. The trays were irrigated with normal tap water using a rubber hose equipped with adjustable pressure sprinkler head. Three additional trays filled with sterilized river sand only were also added to the trial as control. After filling with soil samples and irrigation, all trays were subjected to a pre-chilling treatment at 4 °C for 4 days to break dormancy (Baskin & Baskin, 1988). The trial was irrigated with Hoagland plant nutrient solution (Hoagland, 1932) once every other week to promote good plant growth for easy identification of species. All plants were left to flower and then identified, counted, photographed and removed. Then the test soil layer was turned upside down, stirred and irrigated again. The trial was terminated when only plants with alternative propagules such as bulbs and rhizomes continued to regenerate. The germinable soil seed bank tests extended over a period of 12 months from December to December of 2007/08 and 2008/09, respectively.

The germinable soil seed bank observations were made on three sub-samples of 3 kg each, as explained in the previous paragraph for PSSB.

The species frequency (in %) was calculated based on the number of times a species occurred in the total number of observation units divided by the total number of samples and multiplied by 100. For relative seed density (seed bank size) mean number of seeds and seedlings for each species recorded under each grazing treatment was divided by the total number of individual seeds and seedlings in that treatment and multiplied by 100.

The number of seedlings recorded from the three sub-samples of 3 kg soil used in germinable soil seed bank test is referred to as germinable soil seed bank (GSSB) size. The number of seedlings kg^{-1} soil was used to generate diversity indices and to establish soil seed bank size m^{-2} as explained under PSSB paragraph. At the end of the physical seed extraction and germinable soil seed bank tests, the scientific names and numbers of the plant species, families, functional groups, and palatability categories were recorded for each of the soil samples representing grazing treatment within the 10 range sites.

2.5. Data analysis

From the plant density and species richness data, diversity indices for each grazing treatment within the 10 rangeland sites were generated using the Shannon-Wiener diversity index, the Simpson reciprocal diversity index and the curve fit parameters of the negative binomial equations.

The total number of plant species in a sampling unit is referred to as richness, whereas the total number of individual seeds or seedling representing each species is referred to as PSSB and GSSB bank size, respectively. Shannon's index (H) for a sample is the average degree of uncertainty in predicting the species of an individual chosen at random from a sample, whereas Simpson's index (D) for a sample is the probability that two individuals selected at random will be the same species and the negative binomial based singletons (Sn_1) refers to the number of species present with one individual in an infinitely large sample (Neuteboom & Struik, 2005).

Due to experimental design similarity, the data processing, analysis and presentation methods followed for the aboveground vegetation were also applied on the soil seed bank trial results. The overall flora plant density, richness and diversity indices were subjected to unbalanced accumulated analysis of variance in a completely randomized design with no blocking to test the main effects and interactions of grazing, site and year. For the functional groups, Generalized Linear Model (GLM) with Poisson link was used to model the effects of the grazing treatments on plant density. GLM simplified modeling of large number of plant functional groups representing factors with high variation in plant density in an unbalanced design. To model the effects of grazing on Shannon-Wiener and Simpson reciprocal indices of diversity over sites disaggregated by quadrat and point intercept, *T-test* method was used (Magurran, 1988; Johnson & Kotz, 1969) (Annex 1 to the thesis). Correlation tests was used to assess interdependence between plant population parameters namely density, richness and diversity indices under the grazing treatments within and between sites over years. To assess changes in plant population composition as measured using quadrat and/or point intercept methods within and between sites over years, Morisita-Horn and Sørensen similarity tests were used.

Data were log10 or square roots transformed where coefficient of variation exceeded 30% or scatter plot of residuals and means showed a pattern strongly deviating from a bell shape.

For pair-wise comparison of diversity indices of functional groups, the Simpson index of diversity form was adopted. The standard Simpson's diversity index equation is: $D = \sum_{i=1}^{s} p_i^2$, whereas the Simpson index of diversity (SID) form is (1/D) or $\frac{1}{D} = \frac{1}{\sum_{i=1}^{s} p_i^2}$. The SID form ensures that the value of the index increases with the increase in diversity (Magurran, 1988). p = weighted arithmetic mean of the proportional abundances.

To establish the statistical precision of the pair-wise comparisons of the SID for plant functional groups, their standard variances and errors were calculated using the following procedures (Magurran, 1988).

SE (SID) = $\sqrt{Var(D)}$, where the variance of D is obtained as follows:

$$Var\ (D) = \sum_{i=1}^{s} Var\ (p_i^2) + 2\sum_{i>j}^{s}\sum Cov(p_i^2, p_j^2) = \sum_{i=1}^{s} [\mathrm{E}(p_i^4) - \{\mathrm{E}(p_i^2)\}^2] + 2\sum_{i>j}^{s}\sum[\mathrm{E}(p_i^2\, p_j^2) - \mathrm{E}(p_i^2)E(p_j^2)]$$

where E (.) stands for the expectation of the variable in the parenthesis. We note that the random distribution of (a_1, a_2,….a_s) is assumed to follow a multinomial distribution, a_i is the abundance of species i, and there are i= 1, 2, …s species. Thus using the results of factorial moments and row moments (Johnson & Kotz, 1969), the estimates can be derived as follows:

$Est.E(p_i^2) = p_i^2 + \frac{p(1-pi)}{N} = p_i^2 + p_i(1-p_i)l$, where l =1/N

$Est.\mathrm{E}(p_i^2 p_j^2) = (1-l)(1-2l)(1-3l)p_i^2 p_j^2 + (1-l)(1-2l)lp_i p_j(p_i + p_j) + (1-l)l^2 p_i p_j$ For i ≠ j, the estimated variance of D is:

$$Est\ Var(D) = \sum_{i=1}^{s}[Est\ \mathrm{E}\ (p_i^2) - \{Est\ E(p_i^2)\}^2] + 2\sum_{i>j}^{s}\sum[Est\ E(\ p_i^2, p_j^2) - Est\ E(p_i^2)Est\ E\ p_j^2)]$$

For the expected number of singleton species, the calculations are made using the following equation: $E(S) = \sum_{n=i}^{N=\infty} E(S(n))$, where *E(S)* stands for the total number of species expected $E(S)$ in an indefinite large sample $N = \infty$ predicted from observed number of species referred to as $(n = i)$.

To establish the association between plant population parameters with plant density, the plant species richness and indices of diversity generated using the above statistical procedures were subjected to correlation and similarity tests. The correlation coefficients were generated using the Version 2009.1.02 of Xlstat whereas the similarity indices were generated using the Sørensen and Morisita-Horn equations (Magurran, 2004). The equation of Sørensen quantitative index (abundance) is $C_N = \frac{2jN}{(aN+bN)}$ where aN is the total number of individuals in site A, bN the total number of individuals in site B and *j*N= the sum of the lower of the two abundances for species found in both sites. For Morisita-Horn index (abundance data), the equation used is:

$C_{mH} = \frac{2\sum(\alpha_i*\alpha_i)}{(d_a+d_b)*(N_b*N_b)}$ where N is the total number of individuals at site A and ai is the total number of individuals at site in the ith species in A. $d_a = \frac{\sum a_i^2}{N_a^2}$.

To check on association between the above and belowground flora components, results from the seed bank and aboveground vegetation studies were compared.

3. Results

3.1. Seed bank floristic and functional plant group composition

Based on the PSSB and GSSB studies, a total of 108 taxa from 93 genera and 48 families distributed across the major life span and Raunkiaer plant life form groups were found in the study area. From the 108 identified taxa, 72 species (56 identified and 16 non-identified) and 98 species were recorded through physical seed extraction and germinable soil seed bank tests, respectively (Annex A). The 16 non-identified seed species recorded by physical seed extraction were excluded from the record. Of the 56 identified taxa from 25 families recorded by physical extraction, 70% were annual forbs, 7% annual grasses, 4% perennial forbs, 4% perennial grasses and 16% shrubs. From the germinable soil seed bank test, 98 taxa from 31 families and 72%, 12%, 4%, 3% and 8% of the above life span groups were recorded. T-test showed significant differences ($p<0.01$) between the number of taxa in PSSB and GSSB (Annex B).

Means of species frequencies of occurrence for the most common species (≥1% mean frequency of occurrence) sorted by life span under FP, RG and CG were 22%, 22% and 26% for PSSB and 29%, 30%, 29% for GSSB, respectively. The mean PSSB sizes were 2852 (FP), 1808 (RG) and 2024 (CG) seeds m^{-2}. The means of GSSB size were 420, 294 and 401 seedlings m^{-2}, respectively. The PSSB size of the perennial grass species under CG was zero (Annex B).

The seed of some plant species were present in both the physical and germinable soil seed banks, whereas other ones were present in one of them only. A total of 57% of the species recorded through PSSB were without GSSB. The rate of GSSB without PSSB was 25%. The remaining 18% had both PSSB and GSSB. The mean percentage of species with seeds present in the GSSB only, PSSB only and in both of them were 46%, 10% and 44% with average GSSB sizes of 34, 188 and 25 seedlings m^{-2}, respectively. *Koeleria phleoides* Vill. among the annual grasses and *Carex stenophylla* Wahlenb from the perennial grasses had greater GSSB than PSSB.

3.2. Soil seed bank size (species abundance)

Results of ANOVA on overall floristic PSSB composition, showed season with the highest variance ratio followed by site with a $P<0.001$ significance level for both. Site by grazing interaction was also significant (P<0.018) (Table 2). Significant changes in ranking of treatments for PSSB size were observed in different sites. Out of the 10 sites studied PSSB size was significantly higher under FP than CG in Mahassa, under PF and RG compared to CG at Wadiazeeb1, whereas in Obeisan it was higher under CG than under FP and RG. For the other seven sites, no significant differences in PSSB size between the grazing treatments were observed. However, some general trends could be observed (Fig. 1).

For the life span group, PSSB size was highest under FP, lowest under RG for annual forbs and shrubs, whereas for annual grasses it was lowest under FP and highest under CG and RG treatments. For the perennials, PSSB size was lowest under CG and highest under RG for both forbs and grasses in 2006/07 and for forbs only in 2007/08.

Table 2: Accumulated analysis of variance for physical and germinable soil seed bank size and richness

Method	Change	d.f.	Size		Richness	
			v.r.	F pr.	v.r.	F pr.
Physical seed extraction	Year	2	27.49	<.001	2.17	0.161
	Sites	9	8.81	<.001	1.64	0.216
	Grazing	2	0.01	0.986	1.04	0.387
	Year.Sites	8	2.72	0.063	0.70	0.687
	Year.Grazing	3	1.46	0.279	1.46	0.280
	Sites.Grazing	12	3.74	0.018	0.36	0.955
	% CV		8.5 (log10)		27.8	
Germination test	Year	2	287.34	<.001	29.40	<.001
	Sites	9	23.77	<.001	28.14	<.001
	Grazing	2	0.91	0.432	1.94	0.189
	Year.Sites	8	6.55	0.003	4.22	0.015
	Year.Grazing	3	4.70	0.024	0.96	0.444
	Sites.Grazing	12	3.55	0.022	4.85	0.007
	% CV		9.7 (SQRT)		11.7	

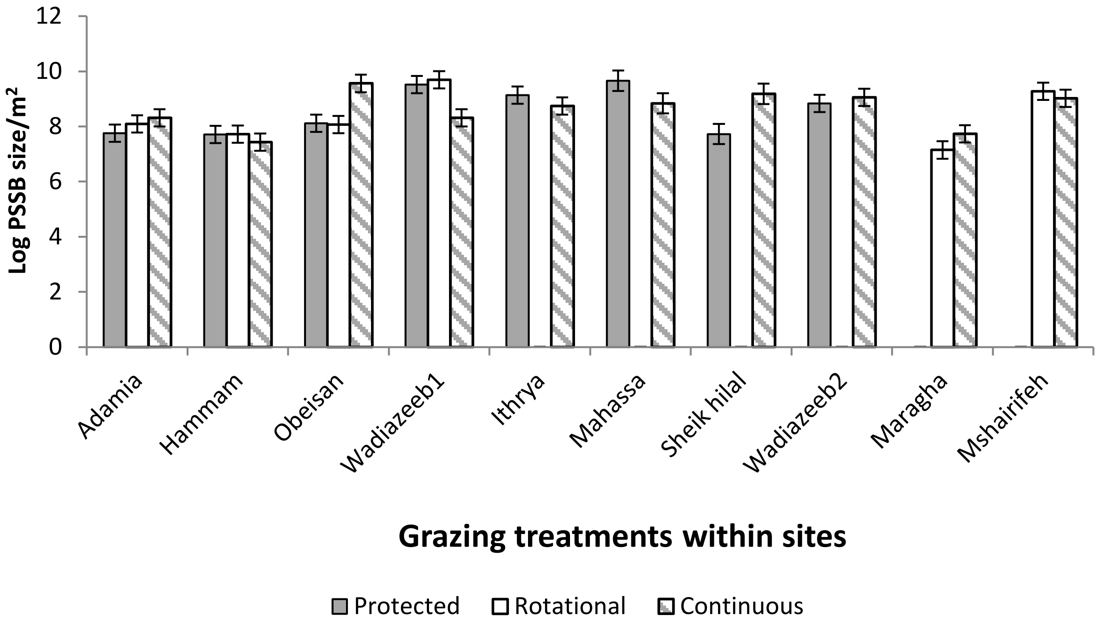

Figure 1: Trend of change in physical soil seed bank size along a grazing gradient of 10 rangeland sites in three consecutive seasons with standard error of mean bars

In the second year of the study, PSSB size was zero under RG and CG for perennial grasses and under the FP and CG treatments sampled in the third year for both perennials (Table 3). Except for therophytes in 2007/08, PSSB size was lowest under RG for all the other life form groups. It was zero under the PF and CG sampled in the third year for geophytes and phanerophytes. For the plant species grouped based on palatability, PSSB was highest under FP for the first and the third season and under RG for the second season.

The ANOVA results on GSSB size showed high variance ratios and F-probability ($P<0.01$) levels for season and site as main effects and a ($P\leq0.05$) for their interactions with grazing (Table 2). These ANOVA outputs indicate significant changes in ranking of treatments within sites. GSSB size was significantly higher under FP compared to RG in Hammam and to CG in Wadiazeeb-2, whereas highest GSSB size was observed under CG in Sheikh hilal and Obeisan and under RG compared to FP in Wadiazeeb1. For the other six sites there were no significant differences between the grazing treatments (Fig. 2). The results also showed significant site-by-season interaction. The ranking of sites for GSSB size significantly changed in the three study seasons and was lowest in 2007/08 for all sites (Fig. 3).

The total annual rainfall in the study areas during 2006/07, 2007/08 and 2008/09 was 126 mm and 90 mm and 129 mm, respectively. The GSSB size was significantly ($P<0.01$) higher in 2006/07 and 2008/09 compared to 2007/08 (Fig. 3).

General trends of change in GSSB size among the individual components of the functional groups along the grazing gradient were also observed. However, the trends of change in GSSB size of different functional groups did not strictly match the trends of change in PSSB size. For the perennial forbs, GSSB size was lowest under RG in which its PSSB size was highest. For the life form and palatability groups, the trend of change in GSSB sizes matched that of the PSSB. GSSB size was highest under RG for geophytes and lowest under it for the other life form groups. The GSSB size was zero for chamaephytes and geophytes under the FP and CG treatments sampled in 2008/09 and for phanerophytes under all treatments (Table 3).

3.3. Soil seed bank species richness

For PSSB species richness, no significant effects were found for the main factors, i.e. year, site, grazing and interactions (Table 2). For GSSB richness, year and site and their interaction were significant, but grazing was not (Table 2). There was a significant change in ranking of treatments within sites for GSSB richness over the two seasons of study. The results showed that GSSB richness was significantly higher ($P<0.007$) under CG than FP at Ithrya and Mshairifeh, under PF than under RG and CG at Hammam and lowest under FP in Wadiazeeb1. For the remaining sites, there were no significant changes in GSSB richness along the grazing gradient (Fig. 4). Moreover, the GSSB species richness was significantly higher ($P<0.05$) in 2006/07 and 2008/09 than in 2007/08 for 7 out of the 10 sites studied (Fig. 5). Wadiazeeb2, Adamia and Mahassa were the three sites for which no significant differences in GSSB were found.

For the overall species composition of PSSB and GSSB, both Simpson reciprocal indices of diversity known as effective number of species (ENS) and Shannon-Wiener diversity indices of were mostly higher under FP followed by CG and lower under RG, particularly in 2007/08 (Table 4). Moreover, pair-wise comparison showed that Simpson reciprocal indices of diversity known as effective number of species for the dominant annual forbs and associated therophytes were highest under FP for PSSB and under RG for GSSB. For the other functional group components no consistent direction of change along grazing gradients within sites and years were found. For perennials and associated life form groups, PSSB and GSSB species richness was zero in 2008/09 (Table 5).

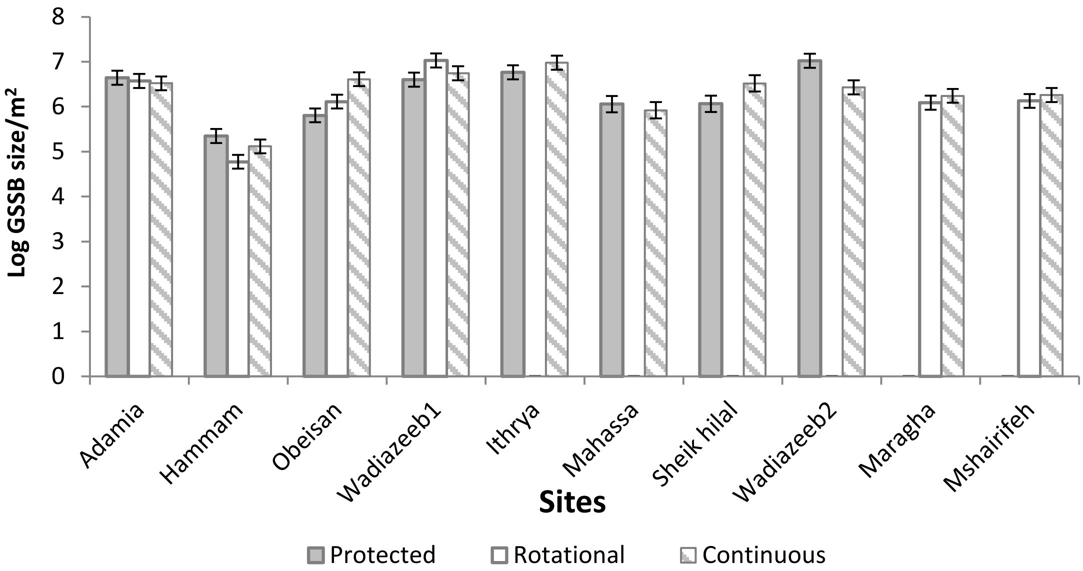

Figure 2: Trend of change in germinable soil seed bank size along a grazing gradient of 10 rangeland sites in three consecutive seasons with standard error of mean bars

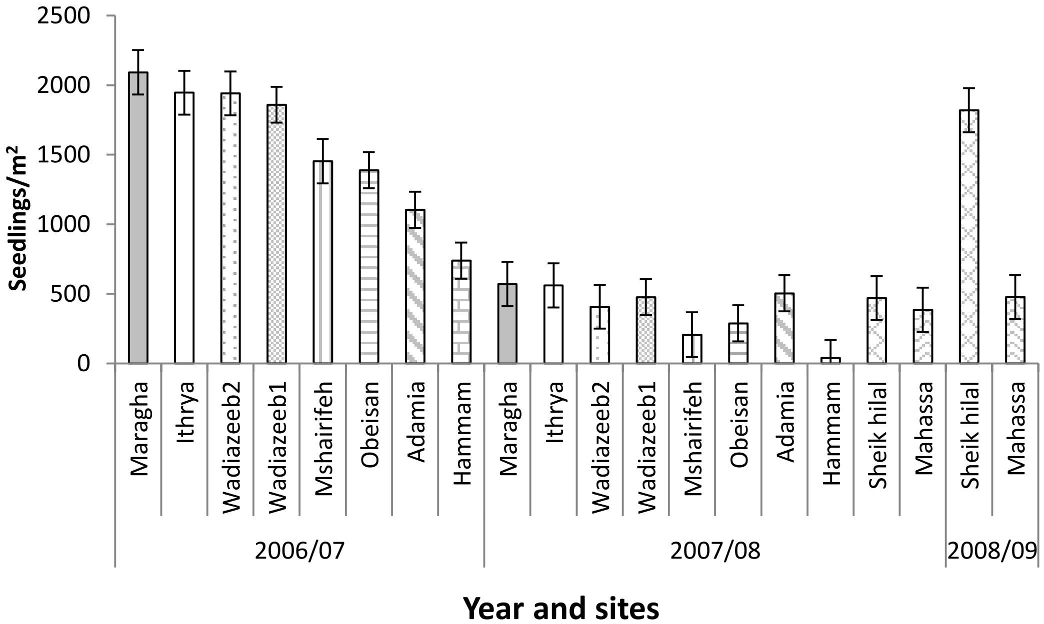

Figure 3: Trends of change in germinable soil seed bank size and richness in two different seasons with standard error of mean bars

Table 3: Mean physical and germinable soil seed bank size along grazing gradients in 10 rangeland sites in northern Syria.

Parameter	Functional group	2006/07			2007/08			2008/09	
		Closed	Managed	Open	Closed	Managed	Open	Closed	Open
Seeds /m2	**Life span**								
	Annual forb	5940±31.5a	4901±28.6c	5502±26.2b	6133±27.7a	5812±30.9c	5988±24.5b	40095±141.6a	12682±79.6b
	Annual grass	119±10.9b	148±8.6b	208±10.2a	188±5.6c	550±11.6a	221±5.6b	3861±43.9b	11763±76.1a
	Perennial forb	327±12.8a	376±11.2a	309±7.8b	223±7.5b	505±15.9a	188±5.6c	0	0
	Perennial grass	59±7.7b	178±13.4a	59±7.7b	119±10.9a	0	0	0	0
	Shrub	208±7.2b	202±6.4b	309±7.8a	257±9.3a	119±6.3c	165±4.3b	89±6.7a	59±7.7a
	Life form								
	Hemicryptophyte	843±13.0a	321±8.0c	423±7.3b	913±10.7a	371±9.6c	568±7.9b	59±7.7a	36±4.6a
	Therophyte	5386±30.0a	4891±28.5b	5331±25.8a	5546±26.3c	6119±31.7a	5833±24.2b	3416±41.1a	59±7.7b
	Chamaephyte	327±12.8a	193±7.0b	285±7.5a	119±10.9a	89±6.7a	95±4.4a	40600±142.5	0
	Geophyte	119±10.9a	119±7.7a	119±10.9a	119±10.9a	0	59±7.7b	0	0
	Phanerophyte	101±14.1a	0	0	59±7.7a	59±7.7a	59±7.7a	0	0
	Palatability								
	High	865±7.7a	728±6.7c	825±7.1b	1275±8.6b	1315±9.5a	1268±8.2b	11016±63.5a	6121±39.8b
	Medium	132±8.6a	111±7.2a	126±8.2a	1132±17.2a	1167±18.7a	1125±17.1a	6759±67.3a	3755±39.1b
	Low	5353±28.4a	4510±26c	5107±24.2b	4939±22.9b	5091±26.8a	4910±20.6c	29650±114.4a	16474±80.7b
Seedlings/m2	**Life span**								
	Annual forb	998±12.9a	741±11.1b	1016±12.1a	216±5.2b	184±5.5c	243±4.9a	993±22.3a	733±19.1b
	Annual grass	241±6.3a	176±5.4c	204±5.1b	31±2.0c	59±3.4b	85±3.1a	213±10.3b	360±13.4a
	Perennial forb	78±3.9a	20±3.2b	74±3.9a	19±2.2a	12±1.8a	9±1.3b	17±4.1a	7±2.6a
	Perennial grass	332±7.4b	384±8.8a	292±7c	101±4.1c	218±7.4a	151±5.5b	0	0
	Shrub	16±2.0a	6±1.2b	25±2.1a	17±1.7a	4±0.8b	7±0.9b	0	0
	Life form								
	Hemicryptophyte	219±6a	194±5.7a	198±5.3a	92±3.6a	71±3.8b	72±3.2b	124±7.9a	109±7.4a
	Therophyte	1194±14.1a	916±12.4b	1260±12.6a	212±5.2b	231±6.2b	305±5.5a	1091±23.4a	987±22.2a
	Chamaephyte	17±2.9a	5±1.6b	27±2.3a	18±3a	5±1.6b	6±0.9b	0	0
	Geophyte	274±7.4a	205±7.2b	176±5.9b	63±3.2c	197±8.1a	89±4.2b	0	0
	Palatability								
	High	249±6.4a	266±6.7a	191±4.9c	94±3.4b	121±4.5a	124±3.5a	147±8.6b	208±10.2a
	Medium	342±9.3a	170±5.8b	147±4.9b	61±2.9b	120.1±4.9a	66±2.9b	117±7.6a	117±7.6a
	Low	1169±14b	844±11.9c	1259±12.5a	197±5b	168.9±5.3c	227±4.8a	950±21.8a	771±19.6b

Standard errors with values less than 0.01 are kept as zero. Different letters within rows of different years indicate significant differences seed bank size

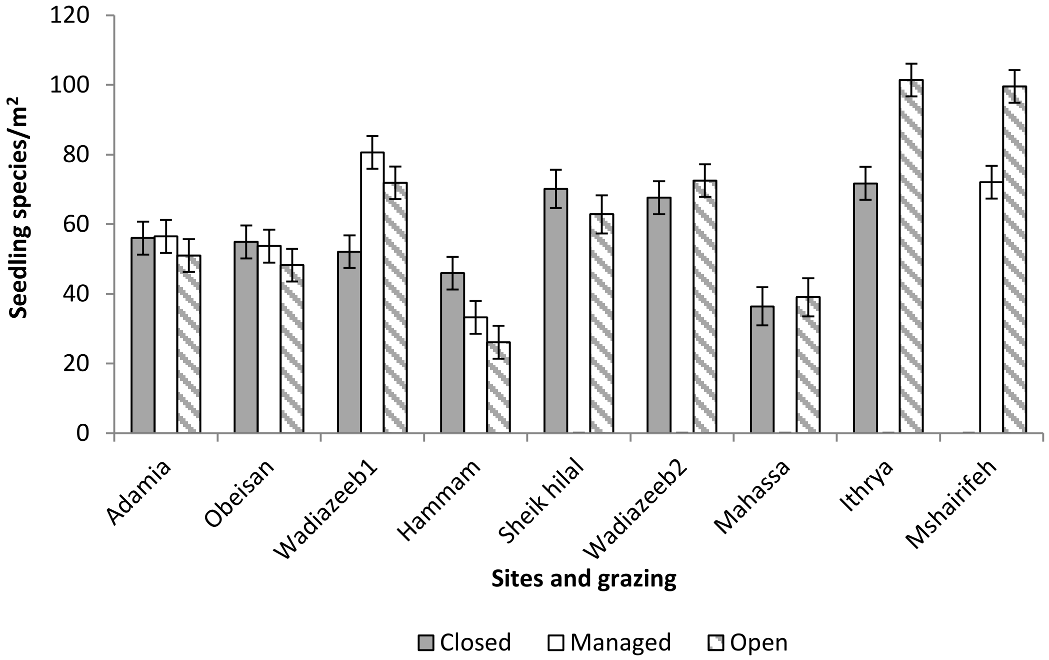

Figure 4: Trends of change in germinable soil seed bank size in three different seasons with their standard error of mean bars

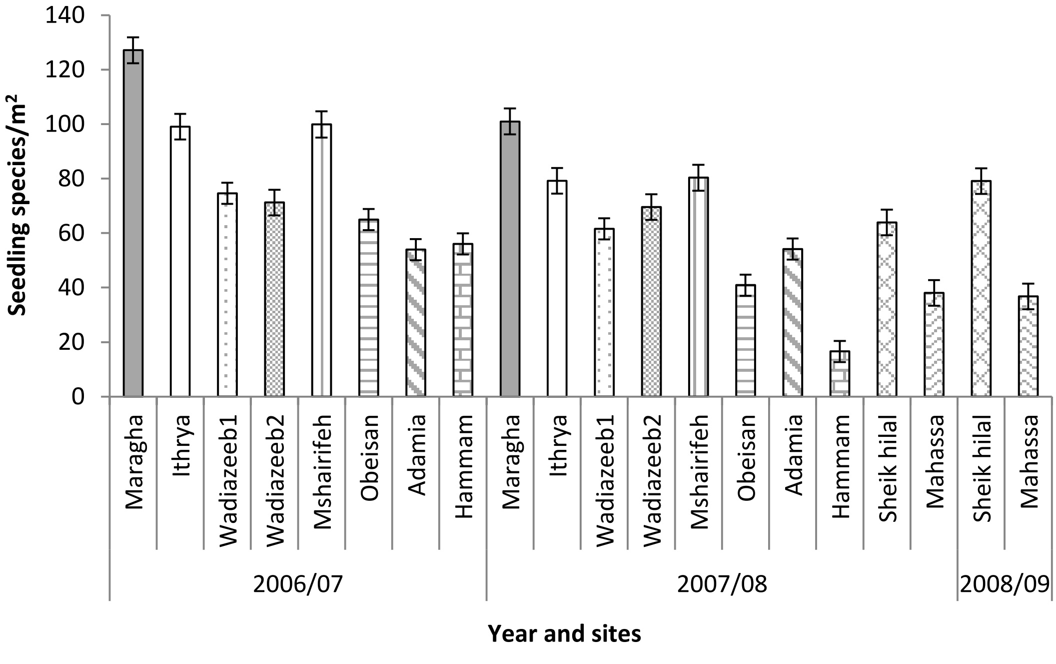

Figure 5: Trends of change in germinable soil seed bank richness in three different seasons with standard error of mean bars

Table 4: Mean Simpson and Shannon-Wiener indices of plant species along grazing gradients within sites for physical and germinable soil seed bank

Sampling method	Diversity indices	Seasons	Grazing treatments		
			Closed	Managed	Open
Seed extraction	Simpson reciprocal indices	2006/07	11.6±0.3[a]	11.8±0.3[a]	11.4±0.2[a]
		2007/08	15.1±0.7[a]	9.6±0.6[b]	14.1±0.5[a]
		2008/09	11.6±0.5[a]	-	10.4±0.5[a]
	Shannon-Wiener	2006/07	2.52±0.05[a]	2.56±0.06[a]	2.24±0.05[b]
		2007/08	2.88±0.03[a]	2.52±0.04[c]	2.78±0.04[b]
		2008/09	1.28±0.04[b]	-	1.70±0.04[a]
Germination	Simpson reciprocal indices	2006/07	7.4±0.5[a]	6.8±0.5[a]	4.3±0.3[b]
		2007/08	13.3±0.6[a]	9.0±0.4[b]	8.6±0.5[b]
		2008/09	2.1±0.1[b]	-	3.5±0.2[a]
	Shannon-Wiener	2006/07	2.82±0.02[b]	2.84±0.02[ab]	2.90±0.02[a]
		2007/08	3.05±0.03[a]	2.85±0.05[b]	3.09±0.03[a]
		2008/09	2.71±0.03[a]	-	2.65±0.04[a]

-: Only sites without rotational grazing treatments were sampled

3.4. Soil seed banks species diversity

For PSSB, the Shannon-Wiener diversity indices were lowest under CG than FP and RG in 2006/07, under RG in 2007/08 and under FP in 2008/09. The change in Shannon-Wiener diversity indices of GSSB was lowest under FP in 2006/07, under RG in 2007/08 and constant in 2008/09 (Table 5).

3.5. Correlations among soil seed bank measurements

Mean PSSB size over grazing and season was significantly correlated with species richness under RG only with a 0.44 coefficient of determination.

Without disaggregating sites into grazing treatments, PSSB size was negatively correlated ($P<0.05$) with both Shannon and Simpson reciprocal indices of diversity, but with low R^2 of 0.085 and 0.081. However, at individual grazing treatment level, PSSB size was negatively correlated with both Shannon ($P<0.01$) and Simpson ($P<0.1$) reciprocal indices of diversity with 0.54 and 0.31 coefficients of determination.

For PSSB, the negative binomial-based Singleton index (S_{n1}) was significantly correlated with species richness with an R^2 range of 0.25 to 0.50. For all treatments, correlations of Shannon and Simpson indices were consistently significant with high coefficients of determination ranging from 0.6 to 0.7 (Table 6).

Mean GSSB size over season and grazing treatment was significantly ($P<0.01$) correlated with richness with a 0.35 coefficient of determination. GSSB size was also correlated with species richness at individual grazing treatment level with 0.33 to 0.55 coefficients of determination. GSSB size was also correlated with Singleton under RG with R^2 = 0.39. For all treatments, correlations of Shannon and Simpson indices were significant with high coefficients of determination ranging from 0.6 to 0.7 (Table 6).

3.6. Seed bank indices of similarity for grazing treatments

The PSSB indices of similarity between FP and RG, FP and CG and RG and CG were respectively 0.38, 0.49 and 0.59 for Morisita-Horn and 0.46, 0.55 and 0.51 for Sørensen. For GSSB, the indices were 0.87, 0.88 and 0.87 for Morisita-Horn and 0.65, 0.72 and 0.64 for Sørensen in the same order (Table 7).

3.7. Similarity of seed bank and vegetation cover measurements

The indices of similarity for PSSB with each of GSSB, quadrat and point intercept measurements were 0.60, 0.08 and 0.26, respectively for Morisita-Horn and 0.60, 0.11 and 0.26 in the same order for Sørensen. For GSSB, the indices of similarity with those of PSSB, quadrat and point intercept over season and grazing treatments, were respectively 0.60, 0.47 and 0.52 for Morisita-Horn and 0.60, 0.19 and 0.60 for Sørensen (Table 8).

Table 5: Simpson reciprocal indices of diversity for physical and germinable soil seed banks along grazing gradients in10 rangeland sites in northern Syria

Parameter	Functional group	2006/07			2007/08			2008/09	
		Closed	Managed	Open	Closed	Managed	Open	Closed	Open
Effective number	**Life span**								
of seed species	Annual forb	6.1±0.4a	5.1±0.4b	3.5±0.2c	10.9±0.5a	6.8±0.3b	6.7±0.4b	1.8±0.1b	4.6±0.3a
	Annual grass	1.0±0a	1.5±0.4a	1.7±0.4a	1.1±0.1b	1.1±0.1b	1.7±0.3a	1.0±0a	1.0±0a
	Perennial forb	1.4±0.3a	1.1±0.1a	1.1±0.1a	1.0±0a	1.0±0a	1.1±0.1a	1.8±0.1b	4.6±0.3a
	Perennial grass	1.0±0a	1.0±0a	1.0±0a	1.0±0a	1.0±0a	1.1±0.1a	1.8±0.1b	4.6±0.3a
	Shrub	1.8±0.4a	2.4±0.6a	1.4±0.2a	1.6±0.4a	3.6±1.4a	3.7±1.1a	1.8±0.7a	1.0±0a
	Life form								
	Hemicryptophyte	1.5±0.1b	2.0±0.3ab	2.1±0.1a	3.0±0.2b	1.9±0.3c	4±0.3a	1.0±0a	1.0±0a
	Therophyte	5.4±0.3a	5.0±0.4b	3.3±0.2c	9.6±0.4a	7.3±0.3b	6.4±0.3c	1.8±0.1b	3.4±0.2a
	Chamaephyte	1.2±0.2a	1.6±0.3a	1.2±0.1a	1.0±0b	1.8±0.7ab	3.6±1.1a	1.0±0	0
	Geophyte	1.0±0a	1.6±0.5a	2.0±1.0a	1.0±0a	1.8±0.7a	1.0±0a	1.0±0	0
	Phanerophyte	1.5±0.1b	1.0±0c	2.1±0.1a	1.0±0a	1.0±0a	1.0±0a	1.0±0a	1.0±0a
	Palatability								
	High	2.4±0.3b	6.4±0.7a	5.1±0.3a	2.9±0.3a	2.0±0.2b	3.3±0.3a	1.7±0.11a	1.0±0.01b
	Medium	5.2±0.3a	1.0±0b	1.0±0b	1.1±0.1b	6.0±0.3a	1.1±0.1b	1.0±0a	1.0±0a
	Low	5.2±0.3a	4.6±0.3a	3.0±0.2b	9.2±0.4a	6.0±0.3b	5.0±0.3c	1.4±0.03b	3.6±0.22a
Effective number	**Life span**								
of seedling species	Annual forb	7.1±0.2b	8.6±0.3a	7.2±0.2b	11.0±0.6ab	13.0±1a	10.5±0.6b	9.2±0.5a	8.2±0.5a
	Annual grass	2.2±0.1a	1.8±0.1b	1.4±0.1c	2.2±0.1a	1.7±0.2b	1.9±0.1ab	2.2±0.1a	2.6±0.1a
	Perennial forb	1.0±0b	1.0±0b	1.2±0.1a	1.0±0a	1.3±0.2a	1.0±0a	1.0±0a	1.0±0a
	Perennial grass	1.8±0b	2.0±0a	2.0±0a	1.9±0.1ab	1.8±0.1b	1.9±0.1a	1.0±0a	1.0±0a
	Shrub	2.0±0.2b	1.9±0.5ab	2.9±0.4a	2.4±0.4a	2.3±0.7a	3.8±1.1a	1.0±0a	1.0±0a
	Life form								
	Hemicryptophyte	2.8±0.1a	1.1±0c	2.1±0.1b	3.6±0.2a	1.5±0.1c	2.4±0.2b	1.1±0.1a	1.1±0a
	Therophyte	8.6±0.2b	10.4±0.3a	8.5±0.2b	11.9±0.7a	13.5±0.9a	10.9±0.5b	10.4±0.5a	9.4±0.5a
	Chamaephyte	1.0±0b	1.8±0.7ab	2.7±0.4a	1.4±0.3a	1.8±0.7a	2.9±0.9a	0	0
	Geophyte	1.0±0a	1.0±0a	1.0±0b	1.0±0a	1.0±0a	1.0±0a	0	0
	Palatability								
	High	4.2±0.3a	2.0±0.1c	2.7±0.2b	4.4±0.3a	3.9±0.3a	4.0±0.3a	1.5±0.13a	1.2±0.07a
	Medium	1.0±0c	1.1±0a	1.1±0a	1.2±0.1a	1.0±0b	1.4±0.1a	1.0±0.03b	1.2±0.08a
	Low	8.1±0.2b	9.0±0.3a	8.4±0.2b	10.8±0.7a	11.4±0.9a	8.9±0.5b	9.1±0.49a	8.7±0.51a

Standard errors with values less than 0.01 are kept as zero

Table 6: Coefficients of determination for plant density, species richness and diversity in 10 rangeland sites with threegrazing treatments in northern Syria

Grazing	Parameters	PSSB					GSSB				
		Size	Richness	Shannon	Simpson	Singletons	Size	Richness	Shannon	Simpson	Singletons
Overall (N=48)	Size	**1**	0.040	**0.085****	**0.081****	0.004	**1**	**0.351*****	0.000	0.010	0.018
	Richness		**1**	0.033	0.000	**0.248*****		**1**	0.002	0.012	0.004
	Shannon			**1**	**0.592*****	0.006			**1**	**0.772*****	0.024
	Simpson				**1**	0.002				**1**	0.040
	Singletons					**1**					**1**
Protected (N=16)	Size	**1**	0.010	0.097	0.098	0.040	**1**	**0.328****	0.001	0.048	0.104
	Richness		**1**	0.120	0.025	**0.495*****		**1**	0.155	0.141	0.062
	Shannon			**1**	**0.600*****	0.059			**1**	**0.785*****	0.066
	Simpson				**1**	0.000				**1**	0.103
	Singletons					**1**					**1**
Rotational (N=12)	Size	**1**	**0.437****	**0.538*****	**0.313***	0.004	**1**	**0.550*****	0.011	0.054	**0.392*****
	Richness		**1**	0.151	0.058	**0.453****		**1**	0.051	0.092	0.007
	Shannon			**1**	**0.688*****	0.006			**1**	**0.692*****	0.005
	Simpson				**1**	0.003				**1**	0.008
	Singletons					**1**					**1**
Continuous (N=20)	Size	**1**	0.089	0.024	0.011	0.000	**1**	**0.373****	0.001	0.012	0.089
	Richness		**1**	0.082	0.021	**0.242****		1	0.000	0.010	0.100
	Shannon			**1**	**0.725*****	0.033			**1**	**0.827*****	0.004
	Simpson				**1**	0.015				**1**	0.056
	Singletons					**1**					**1**

Values in bold are different from 0 with a significance level of correlation at alpha=0.05; *=P<0.1; **=P<0.05, ***=P<0.01

Table 7: Similarity indices for species diversity of physical and germinable soil seed banks along a grazing gradient of 10 arid Mediterranean rangeland sites in northern Syria

Method	Collection method	Grazing	Full protection	Rotational	Continuous
Morisita-Horn	Physical soil seed bank	Full protection	1	0.38	0.59
		Rotational		1	0.49
		Continuous			1
	Germinable soil seed bank	Full protection	1	0.87	0.88
		Rotational		1	0.87
		Continuous			1
Sørensen	Physical soil seed bank	Full protection	1	0.46	0.55
		Rotational		1	0.51
		Continuous			1
	Germinable soil seed bank	Full protection	1	0.65	0.72
		Rotational		1	0.64
		Continuous			1

Table 8: Similarity indices for species diversity of aboveground vegetation, physical and germinable soil seed banks along grazing gradients in 10 rangeland sites in northern Syria

Index	Methods	Quadrat	Point intercept	Germinable seed bank	Physical seed bank
Morisita-Horn	Quadrat	1	0.63	0.47	0.08
	Point intercept		1	0.52	0.26
	Germinable seed bank			1	0.60
	Physical seed bank				1
Sørensen	Quadrat	1	0.21	0.19	0.11
	Point intercept		1	0.60	0.29
	Germinable seed bank			1	0.60
	Physical seed bank				1

4. Discussion

4.1. Seed bank floristic and functional plant group composition

The existence of GSSB without PSSB, for some species, is probably due to difficulties in physically recovering and identifying seed from soil. It was not possible to link the seeds of the 16 species which could not be identified with those in the GSSB. For most of those species, only a few seeds in bad shape were available making it difficult to compare them with seeds in the reference collection harvested from the study areas and greenhouse trials. Moreover, the average GSSB size of this category was 25 seedlings m^{-2} compared to an average GSSB size of 188 seedlings m^{-2} for the species with both soil seed banks. The PSSB without GSSB also had as low as 25 seed m^{-2} average PSSB size and involved three annual forbs and all the phanerophytes shrubs most of which are associated with high physical dormancy and low germination rates under natural conditions. Stevens et al. (2006) reported that 5% successful establishment is not uncommon from field-sown seed of Saltbush in Australia. GSSB without physically recoverable PSSB has been reported (Traba et al., 1998).

Among the GSSBs with low or zero PSSB size were one annual and two perennial grasses, namely *Koeleria phleoides* Vill., *Carex stenophylla* Wahlenb and *Poa bulbosa* L. The perennial species rely on their alternative reproductive systems of bulbs and rhizomes more than seed for regeneration and persistence. For the annual species, the difference in PSSB and GSSB may be attributed to difficulties in extracting and counting the tiny seed size and low population density species from natural soils.

The 108 species recorded from the soil seed banks of the study area represent 52.4% of the 206 floristic steppe plant species reported from a survey on natural resources covering 30% of the 10 million hectare of rangelands in Syria (ACSAD, 2004). Our study was carried out in a small area within one of the three regions covered in the above-mentioned study area.

The statistically higher number of taxa and arithmetically greater number of families recorded in GSSB than in PSSB (Annex B) can be attributed to the fact that seed dormancy is a relative rather than an absolute trait. Both transient and persistent soil seed banks contain viable seed stocks at variable age and types of dormancy from all species that occur in them. It is stated in Baskin & Baskin (1988) that after ripening, seed stocks of up to 88% of plant species are ready to germinate without any additional treatment if favorable soil and climatic conditions prevails. The results of our study show that for tiny seed size and low seed bank density species, the probability of germination under a well-established and managed grow out test is greater than discovering them through physical seed extraction.

Thompson et al. (2003) found that conventional methods of investigating soil seed banks underestimate the persistence of species with dormant seeds and concluded that extraction of naturally buried seeds from soil, followed by determination of viability, is probably the least ambiguous means of estimating longevity. However, attempts at dormant seed recovery from soil samples, identification and quantification after a minimum of one and half season of natural burial with continuous watering, plant removal and soil steering proved impractical (Traba et al., 1998). Peco et al. (1998) reported based on grow out test soil analysis under a magnifying glass, that although the possibility of underestimating the number of species in the soil samples after 9 months of greenhouse germination due to the existence of none germinated dormant seeds cannot be excluded, it seems quite unlikely. Nonetheless, under the controlled environment conditions of our GSSB study, the most likely reason for the significant differences between the PSSB and GSSB sizes of the same species is dormancy-induced persistency. Peco et al. (1998) also reported that no viable seeds could be found through analysis of random fraction of soil samples under a magnifying glass after 8 months of greenhouse germination. Germinable soil seed bank test discriminates between dormancy and environment induced persistence referred to as lack of exposure to favorable germination conditions such as moisture and temperature due to burial depth or other natural insulation mechanisms such as fruit brackets and deep soil cracks. Therefore, the sizable differences between PSSB and GSSB of the same species could be considered as indirect proof of dormancy-induced seed longevity and potential persistency in the soil seed bank (Thompson et al., 1979).

4.2. Soil seed banks species abundance

The higher variance ratio and F-probability of season and site factors compared with grazing is in line with the facts that abundant seed rain from which soil gets its seed bank supply is largely controlled by the soil and environmental ecosystem components. Seed productivity depends on soil moisture (Holzapfel et al., 2006) and site potentialities which are strongly associated with physical and chemical soil integrity (Goodall et al., 2011; Snyman & Preez, 2005), soil fertility (Markus et al., 2005) and topography (Qiuyan et al., 2011; Danin, 1999) and levels of anthropogenic disturbances in a given site such as opportunistic cultivation and overgrazing (Morris et al., 2011; El-Barasi & Buhwarish, 2005).

The interaction between site and grazing for PSSB size was probably due to inherent unevenness of temporal and spatial distribution of rainfall in arid Mediterranean rangelands, anthropogenic disturbances (Table 1) and the high patchiness of plant communities of the arid Mediterranean rangelands. The trend of change in PSSB size was not consistent neither significant among grazing treatments within sites. In a study about grazing effects on plant diversity, Osem et al. (2002), concluded that in the semi-arid Mediterranean rangeland studied, diversity of the annual plant community is determined by the interaction between grazing and small-scale spatial and temporal variation in primary productivity, operating mainly on the less abundant species in the community. Nooralhamad (2006) found similar trends in spatial distribution of plant communities in the Jordanian rangelands subjected to a range of grazing pressure across the area so as to maintain diversity at local and regional scales. Yu et al. (2008) concluded that open patches generally have the greatest species richness, diversity and productivity.

The site in which PSSB size was significantly greater under FP than under CG was Mahassa. The higher PSSB size under FP may be attributed to a greater top soil protection, thus maintaining a higher PSSB size than in the CG area. The two sites for which PSSB size was higher under CG were under continuous cultivation up to time of sampling. The intensive cropping practices including repeated seeding, frequent cultivation and active seed dispersion by sheep and goat flocks are the probable underlying factors for the higher PSSB size than in the CG areas.

The lower PSSB size of annual forbs under RG can be attributed to the higher perennial grass population under the same grazing treatment. The increase in perennials coincided with decrease in annuals and vice versa. This is probably due to root competition over the same soil layer allowing the annuals, particularly the forbs with pivotal root system to proliferate with decline in perennials. There is a similar trend of change in PSSB size under FP. The PSSB size was, in general, higher under FP and RG. This could be attributed to their higher proportion in the natural flora and to the higher seed productivity under FP and RG resulting from reduced soil erosion and potential evapotranspiration usually associated with higher organic matter, debris mulching during the dry period and vegetative cover during the growing season. Huang & Wu (2007) reported grassland desertification accompanied by severe soil erosion, soil nutrition decline and species diversity losses.

The significant decline in PSSB size of perennial grasses under continuous grazing from 178 to 0 seeds m^{-2} and an increased in PSSB size of annual grasses from 610 to 1193 seeds/m^2 under FP and CG, respectively, can be attributed to impacts of overgrazing on the above ground vegetation, the top soil layer and plant ecosystem components. These results are in line with research findings in which perennial grass species dominated the lightly grazed sites, whereas the heavily grazed sites were dominated by annual forbs (Tessema et al., 2012). Continuous and severe grazing increased the abundance of small-seeded, prostrate forbs with round seeds and favored annual grasses over perennial grasses (Dreber et al., 2011). In a study on plant trait responses to grazing–a global synthesis, Díaz et al. (2007) concluded that grazing favored annual over perennial plants. The perennial grasses for which no seeds were found under CG in this study depend more on alternative reproduction mechanisms such as bulbs and rhizomes on their persistence. Heavy grazing during flowering and seed setting are the most probable reasons for the low perennial grasses from the PSSBs, but not from the GSSBs of CG areas.

The trends of change for PSSB along the grazing gradients were rather similar for different life form group species and variable for the life span species. This shows the limited role PSSB dynamics play in the life form group as compared to the life span species. This reflects the greater variations within the life span as compared with life form groups with fewer species within each of them. The reason for the highest PSSB size of all life form groups under FP in the first season is probably because the evolutionary impact is greater than the present grazing impacts on the plant community composition. The life form groups represented in the PSSB are those which are environmentally and evolutionary associated with site characteristics and prevalent grazing systems and herbivores. In absence of grazing, the natural disturbances related to temporal and spatial variations in the ecosystem components of topography, soil and climate tend to maintain a balanced plant community composition within the protected areas for decades (Kansur et al., 2010).

The zero PSSB size of perennials in 2008/09 is probably due to the fact that the two sites sampled are of a desert potentiality with 63-66% sandy soil, 1% organic matter and less than 100mm of annual rainfall. The two sites are dominated with dessert shrubs such as *Aizoon hispanicum* L. and *Haloxylon articulatum* Pomel and ephemerons annuals such *Schismus* and *Astragalus* spp.

The reason for the higher PSSB size of the high palatability species such as legumes could be justified by their relatively higher defoliation resistance resulting from high branching intensity and prostrate growth habit (Noy-Meir & Kaplan, 2002).

The change in GSSB size along the grazing gradient is closely linked to the PSSB floristic and functional plant group composition dynamics. For the Hammam rangeland site in which the GSSB size was greatest under FP, the average PSSB size (seeds m^{-2}) for annual forbs and shrubs was 11.4 and 5.7 under FP compared with 5.6 and 1.3 under RG and 9.2 and 2 under CG. For Wadiazeeb-2, all life span groups were present in the FP areas whereas under CG perennial grasses were missing. The higher GSSB size under CG at Obeisan and Sheikh hilal sites compared to FP and RG was also due to greater PSSB size and/or richness under CG.

The differences in PSSB and GSSB size can be attributed to the plant functional group dynamics controlled by differences in seed physiology and its interaction with ecosystem components related to climate, topography and soil physical characteristics such as compaction and depth resulting from the grazing practices. Perennial grasses and geophytes are *Disporum* type species for which PSSB plays a minor role in reproduction and persistence (Peco et al., 1998). These species had high PSSB and very low GSSP under RG resulting mainly from vegetative propagation. Despite the minor role they play in regeneration, their absence in the PSSB under CG is an indicator of overgrazing. The effects of rangeland ecosystem components on GSSB size have been reported in several investigations. Peco et al. (1998) reported the effects of altitude and topography on autumn seed banks, but did not find any effect of grazing on them. The reason could be the relatively short period of three years and experimental scale at which his research was carried out compared to the decades long and large-scale rangeland rehabilitation areas of our study. Huang et al. (2007) found a decline in species diversity and richness in the plant community and the soil seed bank levels due to soil degradation. During the three years of study, the difference in total annual rainfall was 39 mm and the mean monthly precipitation of the effective winter months of December to March was 16, 23 and 17 mm month^{-1} in year 1, 2 and 3, respectively. These have significantly affected the germinable soil seed bank size and richness. The results from this study are in line with the findings that rainfall, topography and soil texture are the primary drivers of vegetation pattern (Goodall et al., 2011). Seeds in rangeland plots protected from herbivores had significantly higher germination success compared to open plots (Tsegaye et al., 2011).

The significant differences in GSSB size between the grazing treatments followed the trend of change in relative proportions of the plant functional groups among the PSSB size of the grazing treatments within the rangeland sites from which they were collected. Nonetheless, linkage between PSSB and GSSB sizes is not mechanistic but rather depends on species composition which is highly influenced by highly species specific seed physiology characteristics and interactions with topography (Qiuyan et al., 2011), soil type (Madsen et al., 2012), temperature and moisture (Baskin & Baskin, 1988).

The results showed a mismatch in the direction of change for PSSB and GSSB size along grazing gradients within and between rangeland sites. This mismatch is attributable to differences in species and functional group specific seed physiology and interactions with ecosystem components.

4.3. Soil seed banks species richness

The lack of significant differences between the main treatment factors and interactions for PSSB richness showed the high spatial and temporal variability in species richness between sites, seasons and grazing treatments within sites. This emphasizes the relative importance of proportional abundance embedded in the indices of diversity over the simple number of species referred to as richness. The notion of diversity is more than the effective number of species present in an area (Hill, 1973). The lack of significance in the main effects and their interactions on PSSB richness is probably due to the high coefficient of variation resulting from the inherent patchiness of plant populations in the arid Mediterranean rangelands and in the high variations of the temporal and spatial pattern of distribution in precipitation. In a study on the effect of microhabitats on vegetation and their relationships with seedlings and soil seed banks in a Mediterranean coastal sand dune community, Yu et al. (2008) concluded that open patches generally have greater species richness, diversity and productivity than the closed ones.

The significant season-by-grazing and season-by-site interactions for GSSB richness showed clear impacts of environmental factors on soil seed bank dynamics. The results showed that regardless of grazing practices, both spatial and temporal variations in soil and rainfall resulted in significant change in species richness and composition. The low overall physical and germinable soil seed bank richness recorded under RG showed a decrease in effective number of species than FP and CG. The annuals with low soil seed bank size under RG seemed to have more weight on species richness than the dominant perennials under the same treatments. This is an indication of a shift in plant species composition probably moderated by environment and grazing practices towards the higher PSSB and GSSB size perennials with naturally less number of species. This is probably the reason why the lower species richness under RG is more pronounced in the lowest precipitation year of 2007/08. In such seasons the rotational grazing areas are opened for extended period of time to help livestock owners cope with the severe drought associated feed shortage. Teague (2004) reported that the effect of weather, particularly precipitation, dominated changes in herbaceous basal areas. Moreover, the greater GSSB than PSSB richness tendency reconfirms the finding that for 89% and 88% of winter and summer annuals and perennials, seed dormancy is naturally broken by the after-ripening effects of high summer and low winter temperature respectively. Based on the above findings Baskin & Baskin (1988) concluded that temperature, light and moisture were the major environmental factors influencing seed germination and that of the three factors soil temperature across the soil seed bank profile is predominant.

4.4. Soil seed bank species diversity

The fluctuating direction of change in species diversity along the grazing gradient in different sites is also shown in the ANOVA results on PSSB size with significant ($P<0.02$) grazing-by-site interaction. However, for PSSB, no significant differences in species richness were found for any of the three treatment factors or their interaction, namely season, site and grazing. These results show that PSSB size was significantly different in different sites while richness was not. As such, the direction of change in proportional abundance, which is diversity, will be determined by the species abundance ranking pattern in each site. In Obeisan for example, PSSB was highest under CG but diversity was significantly higher under FP. The reason is that under CG, *Herniaria hemistemon* J. Gay dominated with 319 and 121 seed m^{-2} in 2006 and 2007 compared to 3 to 1 seed m^{-2} PSSB size for 7 out of the 10 species recorded in the two respective seasons.

A switch in dominance of species with differences in proportional abundance between the grazing treatments resulted in higher Simpson indices of diversity for GSSB than PSSB under RG. Perennial grasses such as *Carex stenophylla* Wahlenb and *Poa bulbosa* L. had 6.3 and 0 seeds m^{-2} PSSB sizes and 62.5 and 62.5 seedlings m^{-2} GSSB sizes under RG and CG, respectively. The most probable reason is, as explained under the paragraph on richness, heavy grazing during flowering and seed setting. Characterized with high plant density with a mat of roots and bulbs at soil surface, the two species restrict germination and establishment of annuals, particularly grasses, thus reducing their proportional abundance or diversity under RG and FP. This phenomenon is known as lack of gap for germination (Peco et al., 1998). Continuous trampling and wind erosion during the long summer and recurrent winter drought could have contributed to the absence of seed under CG, whereas less soil erosion and lower shading by tall shrubs under RG compared to FP justify their dominance both in PSSB and GSSB.

The examples above show the limitations of absolute plant community parameters such as density, richness and diversity indices. In the above case, the differences in plant density and composition are controlled by plant species represented by entropies or effective number of species present without reference to their relative ecological significance. *Carex* and *Poa* species are high ecological and pasture value plants in the arid Mediterranean rangelands whereas *Herniaria* spp. is a poisonous and severe degradation indicator plant with little or no ecological or pasture values. Relative species diversity based on endemic plant population dynamics monitored against species extinction and invasion seems to be more important than the numeric diversity indices.

The trend of change in GSSB size and diversity along grazing gradients within sites is rather similar to the changes in PSSB discussed above. It seems that the switch in functional plant group domination in PSSB has little or no effect on germination rates. The reason may be the fact that the functional groups involved have germination capabilities proportionate to their relative niches within the plant community resulting from the evolutionary herbivory effects on flora. Both annual and perennial grasses involved in the process of switch in domination had a higher GSSB than PSSB size.

4.5. Correlation among soil seed bank measurements

The relationship between soil seed bank size with species richness is mainly about evenness of species distribution. The highly significant correlation of PSSB size and richness with an R^2 of 0.44 under RG (Table 7) is in line with the higher PSSB size of the major life span groups under RG (Table 3) and the higher overall PSSB diversity indices under RG than under FP and CG (Table 4). In other words, the significant increase in PSSB size of perennials and annual grasses under rotational grazing (Table 3) was associated with a 44% increase in PSSB richness. Nonetheless, the switch in dominance of species with contrasting proportional abundance was reflected in significantly ($P<0.05$) negative correlation between PSSB size with Shannon and Simpson indices of diversity. Fuhlendorf & Engle (2001) found that on productive rangelands with a long evolutionary history of grazing, heterogeneity, in the sense of variability in vegetation stature, composition, density, and biomass, is greatest under moderate grazing on most scales. The predator hypothesis suggests that local prey diversity increases when predators prevent dominant species from monopolizing resources (Paine, 1966). This hypothesis seems to explain the high PSSB and GSSB size under rotational grazing in the arid Mediterranean rangelands. The hypothesis does not apply to the open grazing areas, due to the high grazing intensity considered as the most damaging among the grazing practices (Fuhlendorf & Smeins, 1999), or to the exclosures.

The GSSB size was consistently and significantly correlated with species richness with an R^2 of 0.55 under RG compared to 0.33 and 0.37 under FP and CG, respectively (Table 7). The 0.55 coefficient of correlation and the significantly higher GSSB size of most plant functional groups under RG (Table 7) suggest that 55% of the increase in species richness is due to RG. Higher germination capacity of the above-mentioned dominant species under rotational grazing could be attributed to better seed productivity and quality resulting from better soil conditions and balanced plant density.

4.6. Similarity among soil seed bank measurements

The high Morisita-Horn and Sørensen indices of similarity between PSSB and GSSB and between grazing treatments show a high level of repeatability under the study area and conditions. Of the 25 families recorded in the PSSB, only 3 were not among the 31 families recorded in the GSSB. This suggested that the high similarity indices reflect a real situation on the ground. High similarity between autumn soil seed bank and standing vegetation was found to be associated with domination of annuals as is the case in the research sites of the present study (Peco et al., 1998).

4.7. Similarity between soil seed bank and vegetation cover measurements

The results of similarity tests using both Morisita Horn and Sørensen indices showed a high level of consistency. The results have also shown low physical soil seed bank (PSSB) with both aboveground vegetation measurement methods, namely quadrat and point intercept. This can be attributed to the high labor intensity and difficulties in identifying old weathered seeds recovered from PSSB (Peco et al., 1998). Seeds from 16 species representing one fifth of the total number of species in the PSSB could not be identified. The low similarity between PSSB and GSSB can be attributed to the fact that perennials are better represented in PSSB than in GSSB, in which the perennials seem to be represented by plants from vegetative reproduction with much lower rates than seed germination. Low similarity between soil seed bank and perennial species dominated pastures has been reported (Thompson, 1986).

GSSB showed higher similarity indices than PSSB with both above-ground vegetation measurements, namely quadrat and PI under the study conditions. The high similarity indices between autumn GSSB and standing vegetation has also been reported by others. Peco et al. (1998) attributed it to their high transient seed content resulting from the fresh seed rain of the preceding summer.

4.8. Conclusions

From this study, it can be concluded that

- Impacts of the grazing management component of the rehabilitation program on the floristic composition of the physical and germinable soil seed bank in the study area is strongly moderated by temporal and spatial variability in the biophysical site characteristics and precipitation. This calls for incorporation of herbivory variation and inter-seasonal rotational grazing into the arid rangeland grazing management calendars.
- The simultaneous decline and surge in physical and germinable soil seed bank size of annuals and perennials under the same grazing treatments and sites shows relative differences in root competition and gap exploitation among functional groups. This suggests a plant species facilitation and association relationship between functional groups moderated by the prevalent grazing practices. This is another justification for incorporating herbivore variation to maintain optimum integrity in plant community composition of arid Mediterranean rangelands.
- The study showed a high complementarity of physical and physiological quality based seed extraction and germination methods for soil seed bank assessment. Germinable soil seed bank test neutralizes the seed extraction associated limitations of over/under estimation of soil seed bank size by including none germinable seed and excluding vegetative reproduction propagules. The combination revealed the shift in species with different proportional abundance under the different grazing treatments and sites and the limitations of germination method for phanerophytes. Nonetheless, the grater species richness captured, simplicity and higher similarity indices of germinable soil seed bank with each of physical soil seed bank and vegetation measurements makes it a good monitoring tool for arid rangeland.

Annex A: Floristic and functional species composition of physical and germinable soil seed banks from 10 arid rangeland sites in northern Syria

Life span	Life forms	Family	Species
Annual forb	Geophyte	Liliaceae	Gagea spp.
	Hemicryptophyte	Brassicaceae	Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.
		Geraniaceae	Erodium acaule (L.) Becherer & Thell.
			Erodium glaucophyllum (L.) L'Her.
	Therophyte	Aizoaceae	Aizoon hispanicum L.
		Amaranthaceae	Amaranthus retroflexus L.
		Apiaceae	Bupleurum boissieri Post ex Boiss.
			Bupleurum semicompositum L.
			Coriandrum sativum L.
		Asteraceae	Matricaria aurea (Loefl.) Sch.Bip.
		Boraginaceae	Arnebia tinctoria Forssk.
			Heliotropium europaeum L.
		Brassicaceae	Leptaleum filifolium (Willd.) DC.
		Caryophyllaceae	Gypsophila viscosa Murray
			Herniaria hemistemon J.Gay
			Holosteum spp.
			Holosteum umbellatum L.
			Silene coniflora Otth
			Spergularia diandra (Guss.) Boiss.
			Teucrium parviflorum L.
			Velezia spp.
		Chenopodiaceae	Girgensohnia oppositifolia (Pall.) Fenzl
			Salsola volkensii Schweinf. & Asch.
		Compositeae	Anthemis palestina Boiss.
			Centaurea ammocyanus Boiss.
			Crepis sancta (L.) Bornm.
			Filago desertorum Pomel
			Filago vulgaris Lam.
			Gymnarrhena micrantha Desf.
			Koelpinia linearis Pall.
			Lactuca serriola L.
			Lasiopogon muscoides (Desf.) DC.
			Senecio desfontainei Druce
			Senecio spp.
			Sonchus oleraceus L.
		Crucifereae	Erophila verna (L.) Besser
			Eruca sativa Mill.
			Sisymbrium bilobum (K.Koch) Grossh.
			Sisymbrium spp.
			Torularia torulosa (Desf.) Hedge & J. Leonard
		Dipsaceae	Scabiosa aucheri Boiss.
		Euphorbiaceae	Euphorbia spp.
		Fabaceae	Onobrychis spp.
		Fumariaceae	Fumaria parviflora Lam.
		Labiateae	Lamium amplexicaule L.
			Lamium moschatum Mill.
		Lamiaceae	Ziziphora tenuior L.
		Malvaceae	Malva aegyptia L.
			Malva rotundifolia Desf.
		Papaveraceae	Hypecoum procumbens L.
			Roemeria hybrida (L.) DC.
		Papilionaceae	Astragalus asterias Hohen
			Astragalus spp.
			Hippocrepis unisiliquosa L.
			Lathyrus spp.
			Trigonella aleppica Del.
			Trigonella radiata (L.) Boiss.
			Vicia lutea L.

Annex A: Floristic and functional species composition of physical and germinable soil seed banks from 10 arid rangeland sites in northern Syria (continued)

Life span	**Life forms**	**Family**	**Species**
Annual forbs		Papaveraceae	Papaver syriacum Boiss. & Blanche
		Plantaginaceae	Plantago coronopus L.
			Plantago ovata Forssk.
		Primulaceae	Androsace maxima L.
		Ranunculaceae	Adonis dentata Delile
			Nigella arvensis L.
		Rubiaceae	Crucianella ciliata Lam.
			Galium spp.
		Scrophulariaceae	Linaria chalepensis (L.) Mill.
			Linaria joppensis Bornm.
			Parentucellia viscosa (L.) Caruel
			Veronica persica Poir.
		Sistaceae	Helianthemum aegyptiacum (L.) Mill.
			Helianthemum ledifolium (L.) Mill.
		Umbellifereae	Anisosciadium isosciadium Bornm.
			Torilis leptophylla (L.) Rchb.f.
		Vallerianiaceae	Valerianella spp.
Annual grass	Therophyte	Crassulaceae	Sedum rubens L.
		Gramineae	Aegilops crassa (Zhuk.) Chennav
			Bromus danthoniae Trin.
			Bromus tectorum L.
			Hordeum glaucum Steud.
			Koeleria phleoides (Vill.) Pers.
			Lolium temulentum L.
			Schismus arabicus Nees
			Schismus spp.
			Sphenopus divaricatus (Gouan) Rchb.
			Vulpia myuros (L.) C.C.Gmel.
		Ranunculaceae	Ceratocephalus falcatus (L.) Pers.
Perennial forb	Chamaephyte	Asteraceae	Achillea aleppica DC.
	Geophyte	Liliaceae	Allium spp.
	Hemicryptophyte	Asteraceae	Achillea fragrantissima (Forssk.) Sch.Bip.
		Euphorbiaceae	Andrachne telephioides L.
Perennial grass	Geophyte	Cyperaceae	Sedum rubens L.
	Hemicryptophyte	Gramineae	Poa bulbosa L.
			Stipa barbata auct. non Desf.
Shrub	Chamaephyte	Asteraceae	Artemisia herba-alba
		Chenopodiaceae	Anabasis syriaca Iljin
			Atriplex leucoclada Boiss.
			Chenopodium murale L.
			Haloxylon articulatum Pomel
			Noaea mucronata (Forssk.) Asch.& Schweinf.
			Salsola vermiculata L.
		Frankiniaceae	Frankenia hirsuta L.
		Lamiaceae	Marrubium vulgare vulgare L.
	Hemicryptophyte	Asteraceae	Onopordum anisacanthum Boiss.
		Compositeae	Leontodon arabicum Boiss.
		Scrophulariaceae	Verbascum damascenum Boiss.
		Zygophyllaceae	Peganum harmala L.
	Phanerophyte	Chenopodiaceae	Atriplex halimus L.

Annex B: Species richness, mean percentage frequency of occurrence and size (density) in seed and seedlings m-2 of plant species from different life span groups under full protection, rotational and continuous grazing

Method	Functional group	Species richness		Full protection		Rotational grazing		Continuous grazing		Mean	
		Total	Percentage	%freq.	Size	%freq.	Size	%freq.	Size	%Freq.	Size
Germinable soil seed bank	Annual forb	71	72.4	22.1	26284.1	21.2	16356.6	24.1	16113.4	22.5	19584.7
	Annual grass	12	12.2	17.2	950.4	16.7	514.8	20.0	2474.6	18.0	1313.3
	Perennial forb	4	4.1	18.8	403.9	8.3	475.2	55.0	343.2	27.4	407.4
	Perennial grass	3	3.1	6.3	178.2	4.2	178.2	0	0	3.5	118.8
	Shrub	8	8.2	7.6	1029.6	10.2	594	11.7	920.7	9.8	848.1
	Total	**98**	**100**	**22.2**	**2851.7**	**22.1**	**1807.6**	**26.0**	**2023.7**	**23.4**	**2227.7**
Physical soil seed bank	Annual forb	39	69.6	17.0	1444.3	17.5	957.1	19.9	1395.8	18.1	1265.7
	Annual grass	4	7.1	23.4	298.8	20.1	193.6	23.8	285.3	22.4	259.2
	Perennial forb	2	3.6	62.5	56.5	62.5	15.2	62.5	61.1	62.5	44.3
	Perennial grass	2	3.6	31.3	259.4	39.1	281	27.2	207.6	32.5	249.3
	Shrub	9	16.1	9.4	43.2	12.5	23.9	12.5	57.2	11.5	41.4
	Total	**56**	**100**	**28.7**	**420.4**	**30.3**	**294.2**	**29.2**	**401.4**	**29.4**	**372.0**

%freq: frequency of occurrence

Chapter 4

Bayesian estimation of plant species diversity in arid Mediterranean rangelands under two management systems in northern Syria

This chapter has been submitted to *The Journal of Plant Ecology and Diversity* as:

Bayesian estimation of plant species diversity in arid Mediterranean rangelands under two management systems in northern Syria

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Chapter 4. Bayesian estimation of plant species diversity in arid Mediterranean rangelands under two management systems in northern Syria

Abstract

The diversity of shrubs in rangelands of northern Syria is affected by the grazing management systems. Shrub diversity under two such systems was estimated at two sites using two popular indices, the Shannon index and the Simpson index. These diversity estimates were calculated for the four combinations of two sites (Hammam and Obeisan) and two grazing methods (Closed and Open) using frequentist and Bayesian approaches. We simulated the prior and posterior distributions of the Shannon and Simpson diversity indices. A range of values of a constant in the prior distribution was considered. The values of the constants were chosen to be those which best normalized the distribution of the diversity indices, as reflected by the skewness and kurtosis values. The Bayesian diversity estimates were higher than their frequentist counterparts and had lower standard errors. The grazing methods at each site and sites under each grazing method delivered significant diversity of shrub species. The Bayesian approach resulted in lower p-values than the frequentist approach for two cases reflecting in Bayesian method's higher power based on the priors considered and thus has a wider framework for inference on diversity studies.

Keywords: Species abundance; Species richness; Diversity; Shannon index; Simpson diversity index; Bayesian method

1. Introduction

The arid Mediterranean rangelands are known for their high plant species diversity (Le Houerou, 1981). Due to increased human and livestock population pressure and technological development for exploitation of natural resources, these rangelands are under tremendous threat. The rangelands, established historically as common property resources, are used for grazing by small ruminants, especially sheep and goats. Overgrazing of rangelands by these small ruminants causes degradation (Cesa & Paruelo, 2011; Gamoun et al., 2011; Morris et al., 2011). This leads to reduced performance and a gradual reduction in biodiversity and its spatial distribution (Sanlaville, 2003; Gallacher & Hill, 2006; Nooralhamad, 2006). In addition to overgrazing, wind and irregular rainfall make rangelands fragile and vulnerable to top-soil and plant bio-diversity loss. Suitable rangeland management approaches can be implemented to restore or rehabilitate the diversity (Mourad, 2000; Anon., 2006). Above ground vegetation replenishment depends on aerial seed, rain and viable soil seed banks (Traba et al., 2003; Nicol et al., 2007; Gulden & Shirtliffe, 2009). It is essential to study the status of plant biodiversity in the rangelands under various management practices in order to develop recommendations on the preservation of plant diversity.

A study was undertaken at two sites in the Syrian arid rangelands to investigate the effect of range rehabilitation methods on above ground vegetation density and species diversity. Standard diversity indices such as Shannon index of diversity and Simpson reciprocal diversity index are commonly used instead of the observed plant population density and richness (Magurran, 1988; Pielou, 1975; Patil & Taillie, 1979, 1982). These measures are based on the frequentist approach. Several factors, which underlie the rangeland environment, affect the emergence, reproduction and identification of the emerged plant species and the diversity of the species in that area. With climate change, the biophysical aspects and weather - especially the drought behaviour of the environment - are changing and these changes affect the diversity. Therefore, it is more realistic to consider the prevalence or abundances of the species as random variable rather than assuming a fixed constant. A Bayesian approach, as it is based on distribution of parameters as prior information, is thus more suitable for estimation of the diversity indices. For a set of chosen priors, the objectives of this study were to: 1) describe the diversity in the study regions, b) estimate the diversity using Bayesian method, and c) compare the rangeland grazing management treatments for the changes in the diversity.

2. Materials and methods

A study was undertaken at two sites located within the Aleppo province between the 35.657372N and 37.612917E, and 35.611903N and 37.499980E geographical coordinates. The study was conducted in 2006/07 and 2007/08 using the modified Daubenmire quadrat method (Bonham et al., 2004) and the points intercept method (Cummings, 2001). The areas studied were located within range rehabilitation areas in which continuous grazing, rotational grazing and full protection from grazing had been implemented for about 20 years. We present the analysis of data from the two sites and two grazing managements implemented by the Syrian Steppe Directorate, using halophyte shrub transplanting and rotational grazing. At each site and grazing management combination, a representative macro-plot of 3 ha was used for nine soil samples and grow-out tests were carried out to identify the shrub species and their abundances. The details of the procedures are described by Csontos (2007) and Russi & Cocks (2011). Table 1 presents the observed distribution of the number of individuals per plant species found at the two sites, Hammam and Obeisan, in Syria subjected to two contrasting management practices (closed and open system) in 2007.

Table 1. Distribution of species abundance using growing out method in 2007

Sites	Obeisan				Hammam			
Management	Closed		Open		Closed		Open	
Parameters	Rich-ness	Abun-dance	Rich-ness	Abun-dance	Rich-ness	Abun-dance	Rich-ness	Abun-dance
Plant species	1	82	1	445	1	55	1	69
	1	48	1	51	2	37	1	34
	1	35	1	27	1	33	1	29
	1	34	2	21	1	26	1	10
	1	30	1	12	1	25	1	6
	1	23	2	10	1	20	2	5
	1	17	2	9	1	16	3	3
	1	13	1	8	1	15	1	2
	1	10	2	3	1	10	2	1
	1	9	2	2	2	8		
	1	8	5	1	2	6		
	1	6			1	2		
	1	3			8	1		
	3	2						
	5	1						
Total	13	292	20	589	23	254	13	159

3. Theory and calculations

3.1. Diversity indices

We estimate the diversity using Shannon and Simpson indices (Magurran, 1988) given in the following. In a given year, site (community) and a management system, let there be s plant species with a_i be observed abundance of i-th species, and $N = \sum_{i=1}^{s} a_i$ being the observed total number of individual plants of all the species ($i = 1, 2, ..., s$). Further, denote by $p_i = a_i / N$, the proportion of plants belonging to i-th species. Let π_i be the true but unknown proportion in the population of the *i*-th species at the site/environment under study ($i = 1, 2, ..., s$). The Shannon index of diversity is given by $-\sum_{i=1}^{s} \pi_i \ln(\pi_i)$ and is estimated by $H = -\sum_{i=1}^{s} p_i \ln(p_i)$ and has a standard error of

$$\text{se(H)} = ((\sum_{i=1}^{s} p_i (\ln(p_i))^2 - (\sum_{i=1}^{s} p_i \ln(p_i))^2)/\text{N- (s-1)/(2N}^2))^{1/2}$$

H can alternately be computed as, $H = -\sum_{j=1}^{M} f_j (j/N) \ln(j/N)$ where f_j is the number of species appearing j times; M is the maximum number of appearance of any species. Also $N = \sum_{j=1}^{M} j f_j$

Another measure, Simpson index of diversity (SID) is given in terms of an index called Simpson's D, as $\text{SID} = 1\text{-D}$ where $\text{D} = \sum_{i=1}^{s} p_i^2$. Standard error of SID, se(SID), can be obtained by estimating the square-root of the variance:

$$Var(D) = \sum_{i=1}^{s} Var(p_i^2) + 2\sum_{i<j}^{s} Cov(p_i^2, p_j^2) = \sum_{i=1}^{s} [E(p_i^4) - \{E(p_i^2)\}^2] + 2\sum_{i<j}^{s} [E(p_i^2 p_j^2) - E(p_i^2)E(p_j^2)]$$

In the above, the variance and expected values can be expressed in terms of multinomial distribution parameters (Johnson & Kotz, 1969). The estimates, shown as caps, of various expected values can be given by:

$$\hat{E}(p_i^2) = p_i^2 + p_i(1 - p_i)l$$

$$\hat{E}(p_i^4) = l_1 l_2 l_3 p_i^4 + 6 l_1 l_2 l p_i^3 + 7 l_1 l^2 p_i^2 + l^3 p_i$$

$$\hat{E}(p_i^2 p_j^2) = l_1 l_2 l_3 p_i^2 p_j^2 + l_1 l_2 l p_i p_j (p_i + p_j) + l_1 l^2 p_i p_j, (i \neq j)$$

Where $l = 1/N, l_i = 1 - il, i = 1, 2, 3.$

3.2. Bayesian method and estimation of diversity index

The Bayesian setting requires an estimation of parameters of the proportion of abundance of each species within a system of given number of species and the total abundance (N). Distribution of $(a_1,...,a_s)$ can be seen as multinomial distribution with $s-1$ components with s proportions $(\pi_1,\pi_2,...,\pi_s)$ where $\pi_s = 1-\sum_{i=1}^{s-1}\pi_i$. We briefly describe a Bayesian method for estimation of a single parameter say θ using an observed data vector say $y=(y_1,...,y_n)'$. In our case, e.g., θ may stand for π_i ($i=1,2,...,s$). Let the probability in case of discrete distribution or the likelihood of observing y based on a value of the parameter θ be given by $f(y|\theta)$, called likelihood of y which is a function of θ In Bayesian framework, one introduces a degree of belief in the parameter θ in terms of its probability distribution function say $g(\theta)$, called a prior for θ. The inference about θ is obtained in terms of the probability distribution of θ given the data y and is expressed as $f(\theta|y) \propto g(\theta)f(y/\theta)$, and called the posterior density function of θ, which is obtainable from the famous Bayes' Theorem available in standard texts (Gelmann et al., 2004; Robert & Casella, 2004; Ntzoufras, 2009). Using this posterior density, one can obtain the expected value of θ as an estimate of θ, standard error and its confidence intervals. In case of multiple parameter situation, say $\underline{\theta}=(\theta_1,\theta_2,...,\theta_r)$, as is the present case, the generalization of posterior distribution of θ_k say, based on an assumed joint prior $g(\underline{\theta})$, is given by

$$f(\theta_k \mid y) = \int...\int g(\underline{\theta})f(y|\underline{\theta})d\theta_1...d\theta_{k-1}d\theta_{k+1}...d\theta_r \,/ \int...\int g(\underline{\theta})f(y|\underline{\theta})d\theta_1...d\theta_r$$

There are numerical challenges in the evaluation of the multiple integral required in Bayesian estimation, and these challenges are addressed in vast resources of algorithmic tools and computational codes; see, for example, Gelman et al. (2004), Ntzoufras (2009) and Albert (2009).

In the present context, we proceed as follows. For a fixed N, we assume a multinomial distribution of $(a_1,...,a_s)$ with parameter vector $\underline{\pi}=(\pi_1,\pi_2,...,\pi_s)'$ where $\pi_s = 1-\sum_{i=1}^{s-1}\pi_i$. The probability function of these is given by

$$p(a_1,...,a_s;N;\pi_1,\pi_2,...,\pi_s) = N!\pi_1^{a_1}\pi_2^{a_2}...\pi_s^{a_s}/(a_1!a_2!...a_s!), \text{ when } \sum_{i=1}^{s}a_i = N, \text{ and} = 0, \text{ otherwise.}$$

The marginal distribution of $a_i \sim \text{Binomial}(N,\pi_i)$. A Dirichlet distribution is commonly used as a prior for proportions in components of a system. We assume that $\underline{\pi}=(\pi_1,\pi_2,...,\pi_s)'$ follow $s-1$dimensional Dirichlet distribution with parameter vector $\underline{\alpha}=(\alpha_1,\alpha_2,...,\alpha_s)'$, where $\pi_s = 1-\sum_{i=1}^{s-1}\pi_i$. The prior probability density function (pdf) of the Dirichlet distribution of the random proportions $\underline{\pi} = (\pi_1, \pi_2, ..., \pi_s)'$ of the *i*-th species is

$$f(\pi_1, \pi_2, ..., \pi_{s-1}; \alpha_1, \alpha_2, ..., \alpha_s) = \Gamma(\sum_{i=1}^{i=s} \alpha_i)\ \pi_1^{\alpha_1 - 1} \pi_2^{\alpha_2 - 1} ... \pi_s^{\alpha_s - 1} / \prod_{i=1}^{i=s} \Gamma(\alpha_i), \text{where } \pi_i > 0, \sum_{i=1}^{s-1} \pi_i < 1, \pi_s = 1 - \sum_{i=1}^{s-1} \pi_i, \text{ and,}$$
$$= 0 \text{ otherwise}$$

In above, the random variable and its assumed value is denoted by the same symbol. In this case, it is easy to see that posterior of $\underline{\pi} = (\pi_1, \pi_2, ..., \pi_s)' \mid (a_1, ..., a_s)$ is also a Dirichlet distribution with parameter vector $\underline{\beta} = (\alpha_1 + a_1, \alpha_2 + a_2, ..., \alpha_s + a_s)'$ with the pdf given by

$$f(\pi_1, \pi_2, ..., \pi_{s-1} \mid a_1, a_2, ..., a_s) = \Gamma(\sum_{i=1}^{i=s} \alpha_i + a_i)\, \pi_1^{\alpha_1 + a_1 - 1} \pi_2^{\alpha_2 + a_2 - 1} ... \pi_s^{\alpha_s + a_s - 1} / \prod_{i=1}^{i=s} \Gamma(\alpha_i + a_i), \text{ where } \pi_i > 0, \sum_{i=1}^{s-1} \pi_i < 1, \pi_s = 1 - \sum_{i=1}^{s-1} \pi_i, \text{ and,}$$
$$= 0 \text{ otherwise}$$

Thus, the above prior is a conjugate prior. A frequentist estimate of π_i, based on maximum likelihood estimate or method of moments is given by $p_i = a_i / N$, while an a-priori estimate would be $\alpha_i / \sum_{i=1}^{s} \alpha_i$. Using the above prior on π_i's, the posterior estimate/expectation of π_i is given by $E(\pi_i \mid a_1, ..., a_s) = E(\pi_i \mid a_i) = (a_i + \alpha_i)/(N + \alpha_0)$, where $\alpha_0 = \sum_{i=1}^{s} \alpha_i$. While the posterior distribution of $\underline{\pi} = (\pi_1, \pi_2, ..., \pi_s)'$ is available in exact form, the posterior distribution of H or SID is not. However, its distribution can be simulated using the random values of $\underline{\pi} = (\pi_1, \pi_2, ..., \pi_s)'$ using the Dirichlet distribution with parameter vector $\underline{\beta} = (\alpha_1 + a_1, \alpha_2 + a_2, ..., \alpha_s + a_s)'$. The expressions for exact mean and variance of the Shannon index has been given by Gill & Joanes (1979) where α_i's are kept constant. Realizing the fact that posterior estimates of π_i's depend on α_i's also, it may be worthwhile to allow variation in α_i's. Since the α_i's are predetermined known values, we can have various models to choose from. There are many theoretical models for π_i's such as random uniform model, geometric series, logarithmic series, broken stick model, Zipf-Mandelbrot model etc. (Magurran, 1988; Chao & Shen, 2003). We therefore take the following three classes of priors for choosing α_i's: 1) constant (α_i =1, 3, 5 or 10 for all the species), 2) α_i unequal derived as a random sample from uniform (0.5, k) where k =1, 3, 5, 10, and 3) geometric series and kept within a chosen range given by $\alpha_i = low + (high - low)(r^{(i-1)} - r^{(s-1)})/(1 - r^{(s-1)})$, where the four sets of values (low, high, r) were (1, 2, 0.2), (1, 3, 0.2), (1, 3, 0.8), (5, 10, 0.5). The number of simulation runs was taken as 10000. The computations were carried out using R-language and the codes used are available on request.

3.3. The estimates of diversity indices

Using the selected values of α_i in the Dirichlete distribution as prior parameters to obtain the resulting posterior distribution of H and SID, simulations were used to obtain the required probability density function and summary statistics such as mean, median and 95% confidence limits.

4. Results

For the four combinations of the sites (Hammam and Obeisan) and grazing methods (Closed, Open), observed number of shrub species were: 23 under the closed area (no grazing), referred to as ‘Closed’, and 13 under an area open for grazing at Hammam, referred to as ‘Open’, while at Obeisan, the number of species found were 21 and 20 under Closed and Open grazing systems, respectively (Table 1). The maximum number of abundances varied from 55 to 445 over the four combinations. We simulated the distributions of H and SID based on the prior distribution and posterior distribution of $\underline{\pi} = (\pi_1, \pi_2, ..., \pi_s)'$ and presented in terms of density plots and mean, standard deviation, skewness, kurtosis and quantiles (Figs 1-3 a, b). For α_i=1, 3, 5, 10 (*i*=1,…,s), the posterior distributions of H and SID at Hammam showed a shift to the left of their prior distributions (Figs 1a, b). For α_i=1, the prior distributions covered the range of values of the diversity indices under posterior distribution. The distribution patterns were similar for both the grazing management methods. Thus α_i =1 was chosen for the prior distribution of H and SID. Figs 2a, b show the prior and posterior distribution of the diversity indices when α_i were chosen from as a sample from Uniform (0.5, *k*) where *k* = 1, 3, 5, 10. For this site, the two distribution curves overlap reasonably well for all these choices of *k*. Similarly for values of α_i from the geometric series, Figs 3a, b (for the four combinations of the rate parameter and the range limits), in majority of cases, the overlap between the prior and posterior distribution takes place for the range of the indices. A wider spread in the prior distribution can be noticed in comparison with the posterior distribution.

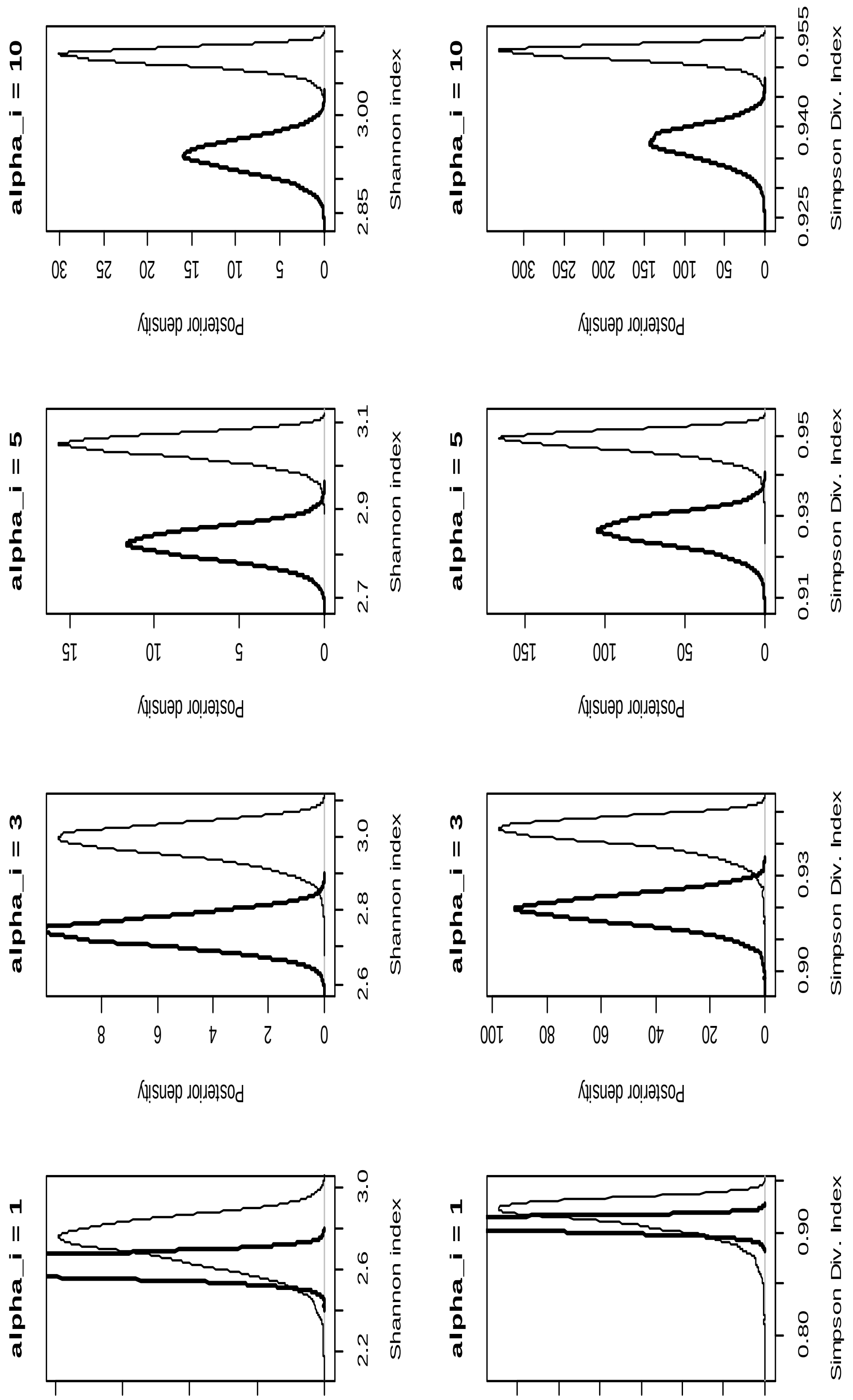

Fig. 1a. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (alpha_i in the figures) = 1, 3, 5, 10 for Closed grazing management system at Hammam (2007)

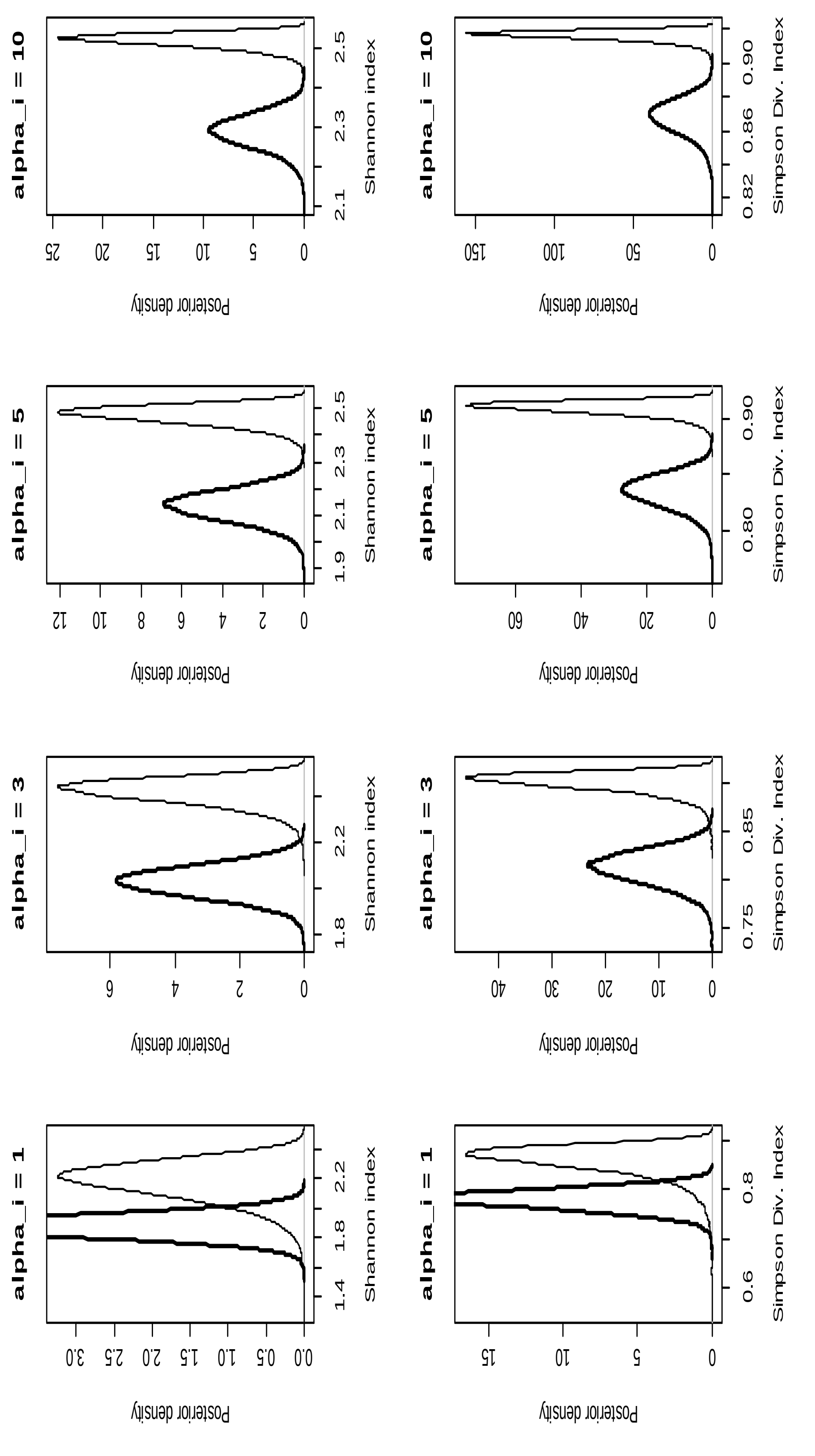

Fig. 1b. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (alpha_i in the figures) = 1, 3, 5, 10 for Open grazing management system at Hammam (2007)

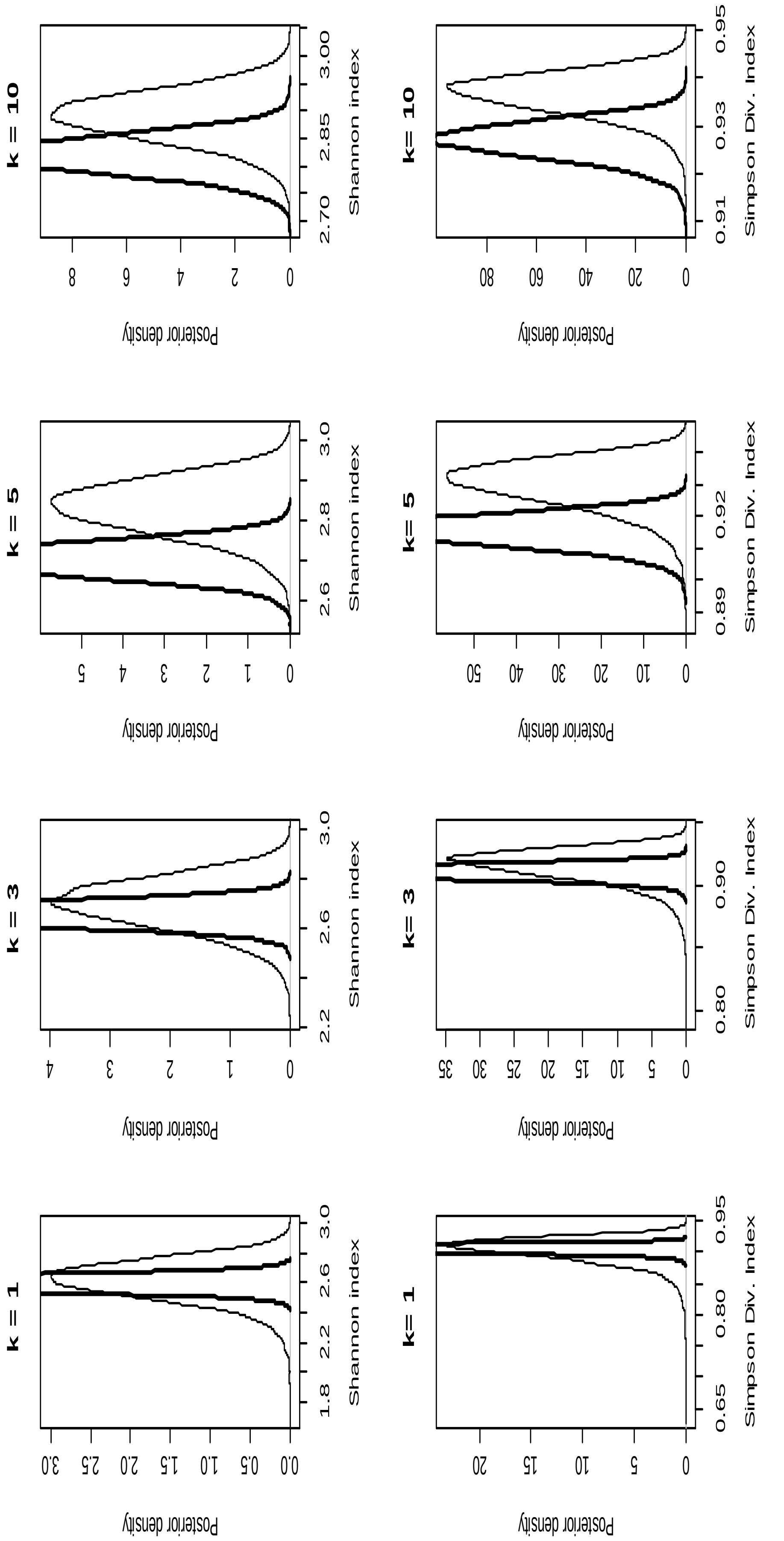

Fig. 2a. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (unequal) obtained as a random sample from uniform distribution (0.5, k), k = 1,3, 5, 10 for Closed management system at Hammam (2007)

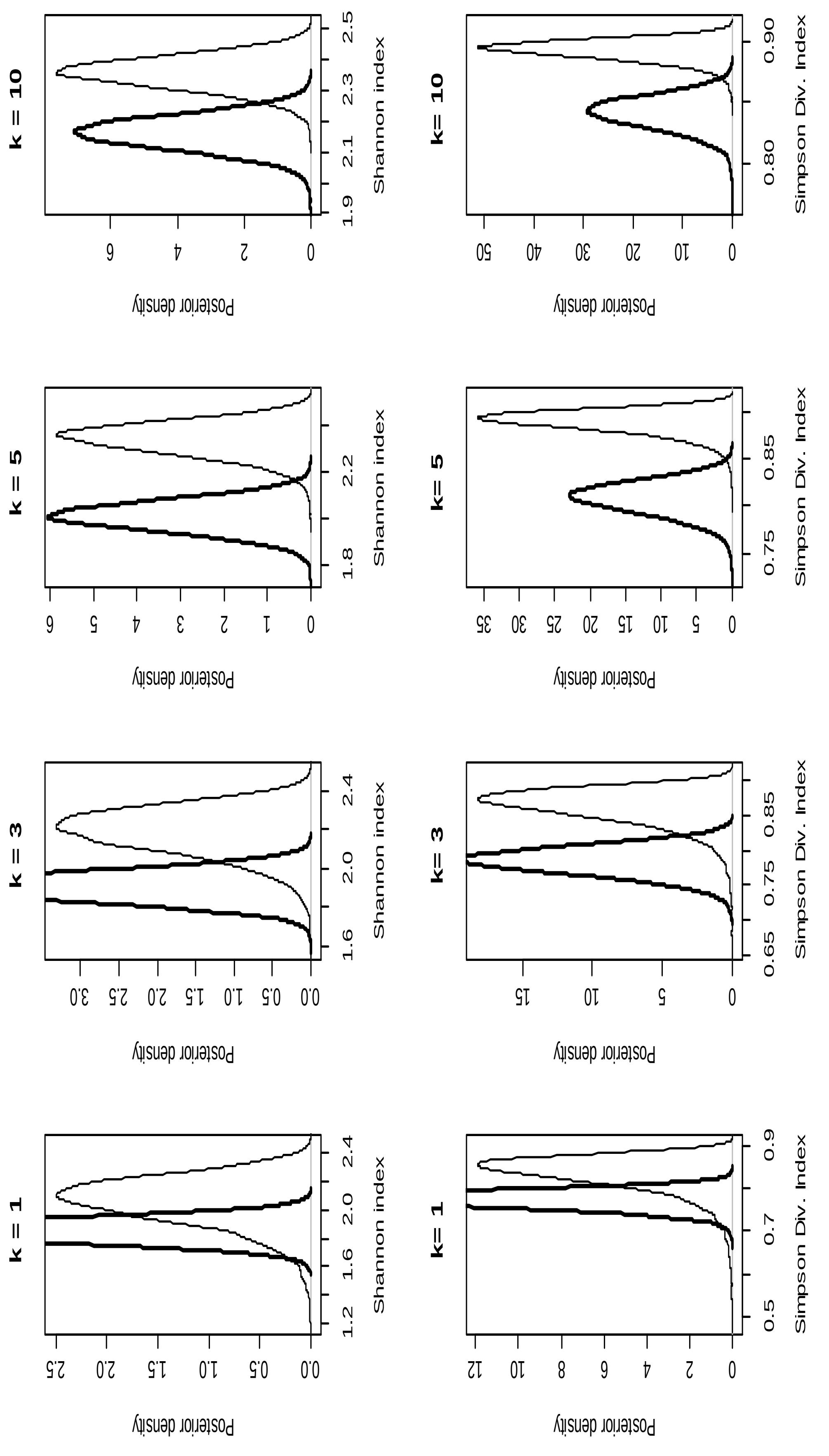

Fig.2b. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (unequal) obtained as a random sample from uniform distribution (0.5, *k*), *k* = 1,3, 5, 10 for Open management system at Hammam (2007)

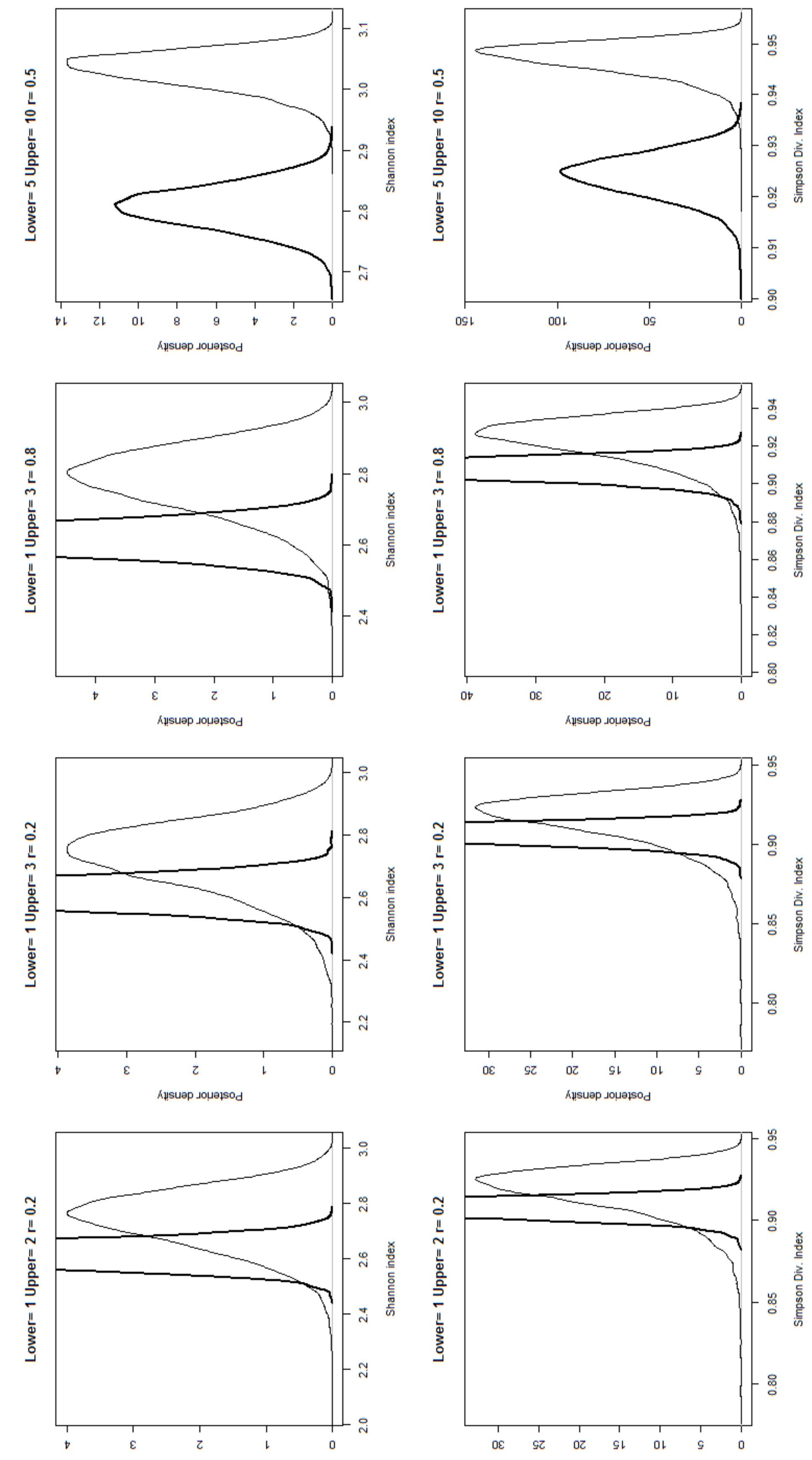

Fig. 3a. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (unequal) obtained as a geometric series (Lower, Upper, r) for Closed management system at Hammam (2007).

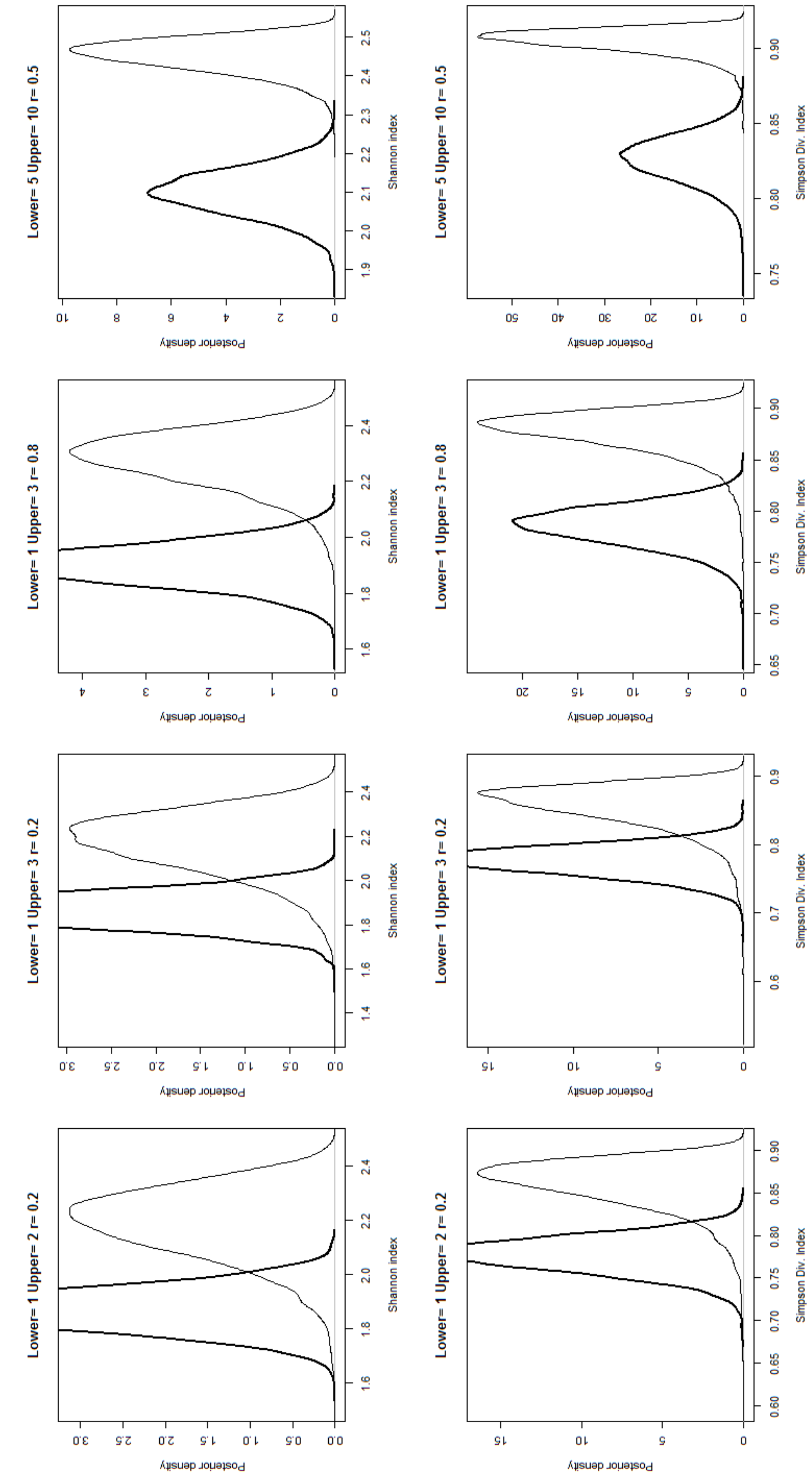

Fig. 3b. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (unequal) obtained as a geometric series (Lower, Upper, r) for Open management system at Hammam (2007)

4.1. The choice of α_i

Although any of the parameters determining the prior distribution could be taken, however, to determine α_i, we identified those parameter values where these graphs for Hammam showed a high degree of overlap with the prior. Although the data should not determine the prior distribution, the overlap consideration pointed to the information for choosing a more reasonable prior than taking arbitrarily from a much wider range of priors. The results on the posterior estimates of diversity indices are presented for the selected priors (Figs 4-6). The summary statistics of the distribution, mean, standard deviation, skewness, kurtosis, quantiles at 2.5%, median and 97.5% are presented in Table 2. This shows that prior distribution of H/SID have larger skewness and kurtosis compared to the posterior distributions. As can be expected there is a difference between prior and posterior distributions based on the selected values of α_i. However, the three posterior distributions also showed differences. For Hammam under Closed system, the mean H and SID varied, over the three priors, in the range 2.60-2.62 and 0.91-0.92, respectively (Table 2). The 95% confidence intervals for H were (2.51, 2.69), (2.53, 2.61) and (2.53, 2.70) for the three priors α_i ($i = 1 \ldots s$) from Uniform (0.5, 3), geometric series (rate = 0.2, low =1 , high = 3) and equal value fixed at 1, respectively.

Table 2. Posterior distribution summary for diversity indices based on selected prior distributions. Methods: Uniform means a random sample of α_i (i=1,2…s) from Uniform distribution (0.5, 3), Fixed means where each α_i was equal to 1; Geometric means α_i s follow geometric series with rate r = 0.2 and cover the range (1, 3). SSSK= sum of squares of skewness and kurtosis $\gamma_1^2+\gamma_2^2$. H: Shannon index. SID: Simpson index of diversity. Low95%/Upp95% = lower/upper 95% confidence limit.

Site	Grazing	Mean	SD	Skewness	Kurtosis	SSSK	Low95%	Median	Upp95%	Method@	Index	Distribution
Hammam	Closed	2.61	0.132	-0.61	0.72	0.89	2.32	2.63	2.84	Uniform	H	Prior
Hammam	Closed	2.72	0.110	-0.63	0.77	0.99	2.48	2.73	2.91	Geometric	H	Prior
Hammam	Closed	2.73	0.105	-0.61	0.82	1.04	2.51	2.74	2.91	Fixed	H	Prior
Hammam	Closed	2.60	0.044	-0.07	0.05	0.01	2.51	2.60	2.69	Uniform	H	Post
Hammam	**Closed**	**2.61**	**0.043**	**-0.04**	**0.08**	**0.01**	**2.53**	**2.61**	**2.70**	**Geometric**	**H**	**Post**
Hammam	Closed	2.62	0.043	-0.10	-0.04	0.01	2.53	2.62	2.70	Fixed	H	Post
Hammam	Closed	0.90	0.021	-1.65	5.06	28.31	0.85	0.91	0.93	Uniform	SID	Prior
Hammam	Closed	0.91	0.017	-1.69	5.56	33.80	0.87	0.92	0.94	Geometric	SID	Prior
Hammam	Closed	0.92	0.015	-1.55	5.36	31.19	0.88	0.92	0.94	Fixed	SID	Prior
Hammam	Closed	0.91	0.005	-0.38	0.34	0.26	0.90	0.91	0.92	Uniform	SID	Post
Hammam	Closed	0.91	0.005	-0.36	0.39	0.28	0.90	0.91	0.92	Geometric	SID	Post
Hammam	**Closed**	**0.91**	**0.005**	**-0.38**	**0.33**	**0.25**	**0.90**	**0.91**	**0.92**	**Fixed**	**SID**	**Post**
Hammam	Open	2.09	0.155	-0.66	0.77	1.03	1.74	2.11	2.35	Uniform	H	Prior
Hammam	Open	2.16	0.140	-0.71	0.86	1.24	1.85	2.18	2.39	Geometric	H	Prior
Hammam	Open	2.18	0.134	-0.73	0.96	1.46	1.87	2.20	2.40	Fixed	H	Prior
Hammam	**Open**	**1.86**	**0.075**	**-0.04**	**0.02**	**0.00**	**1.71**	**1.86**	**2.01**	**Uniform**	**H**	**Post**
Hammam	Open	1.87	0.076	-0.05	-0.04	0.00	1.72	1.87	2.02	Geometric	H	Post
Hammam	Open	1.88	0.074	-0.13	-0.02	0.02	1.73	1.88	2.02	Fixed	H	Post
Hammam	Open	0.84	0.039	-1.58	4.55	23.24	0.74	0.85	0.89	Uniform	SID	Prior
Hammam	Open	0.85	0.035	-1.67	5.46	32.59	0.77	0.86	0.90	Geometric	SID	Prior
Hammam	Open	0.86	0.032	-1.72	6.15	40.75	0.78	0.86	0.90	Fixed	SID	Prior
Hammam	Open	0.78	0.021	-0.33	0.31	0.21	0.73	0.78	0.81	Uniform	SID	Post
Hammam	**Open**	**0.78**	**0.021**	**-0.35**	**0.21**	**0.17**	**0.73**	**0.78**	**0.81**	**Geometric**	**SID**	**Post**
Hammam	Open	0.78	0.020	-0.41	0.31	0.26	0.74	0.78	0.82	Fixed	SID	Post
Obeisan	Closed	2.53	0.137	-0.65	0.84	1.13	2.22	2.54	2.76	Uniform	H	Prior
Obeisan	Closed	2.63	0.116	-0.66	0.79	1.05	2.37	2.64	2.83	Geometric	H	Prior
Obeisan	Closed	2.65	0.109	-0.66	0.92	1.27	2.40	2.66	2.83	Fixed	H	Prior
Obeisan	**Closed**	**2.41**	**0.049**	**-0.01**	**0.02**	**0.00**	**2.32**	**2.41**	**2.51**	**Uniform**	**H**	**Post**

Table 2 (continued)

Site	Grazing	Mean	SD	Skewness	Kurtosis	SSSK	Low95%	Median	Upp95%	Method@	Index	Distribution
Obeisan	Closed	2.43	0.048	-0.05	0.01	0.00	2.34	2.43	2.53	Geometric	H	Post
Obeisan	Closed	2.44	0.048	-0.10	0.03	0.01	2.34	2.44	2.53	Fixed	H	Post
Obeisan	Closed	0.89	0.024	-1.69	5.42	32.20	0.83	0.90	0.93	Uniform	SID	Prior
Obeisan	Closed	0.91	0.019	-1.59	4.54	23.13	0.86	0.91	0.93	Geometric	SID	Prior
Obeisan	Closed	0.91	0.017	-1.70	6.51	45.22	0.87	0.91	0.93	Fixed	SID	Prior
Obeisan	**Closed**	**0.88**	**0.008**	**-0.31**	**0.17**	**0.13**	**0.86**	**0.88**	**0.89**	**Uniform**	**SID**	**Post**
Obeisan	Closed	0.88	0.008	-0.34	0.17	0.15	0.86	0.88	0.89	Geometric	SID	Post
Obeisan	Closed	0.88	0.008	-0.44	0.33	0.30	0.86	0.88	0.90	Fixed	SID	Post
Obeisan	Open	2.48	0.140	-0.68	0.97	1.40	2.16	2.49	2.71	Uniform	H	Prior
Obeisan	Open	2.58	0.119	-0.72	1.20	1.95	2.32	2.59	2.78	Geometric	H	Prior
Obeisan	Open	2.60	0.113	-0.62	0.62	0.77	2.34	2.61	2.78	Fixed	H	Prior
Obeisan	Open	1.39	0.060	0.04	0.00	0.00	1.27	1.39	1.50	Uniform	H	Post
Obeisan	**Open**	**1.41**	**0.061**	**0.01**	**-0.01**	**0.00**	**1.29**	**1.41**	**1.53**	**Geometric**	**H**	**Post**
Obeisan	Open	1.41	0.061	0.01	-0.05	0.00	1.29	1.41	1.53	Fixed	H	Post
Obeisan	Open	0.89	0.026	-1.79	6.34	43.45	0.82	0.89	0.92	Uniform	SID	Prior
Obeisan	Open	0.90	0.021	-1.85	7.22	55.59	0.85	0.91	0.93	Geometric	SID	Prior
Obeisan	Open	0.90	0.019	-1.55	4.48	22.49	0.86	0.91	0.93	Fixed	SID	Prior
Obeisan	**Open**	**0.52**	**0.023**	**-0.01**	**0.00**	**0.00**	**0.48**	**0.52**	**0.57**	**Uniform**	**SID**	**Post**
Obeisan	Open	0.53	0.023	-0.04	0.02	0.00	0.48	0.53	0.57	Geometric	SID	Post
Obeisan	Open	0.53	0.023	-0.03	-0.05	0.00	0.48	0.53	0.57	Fixed	SID	Post

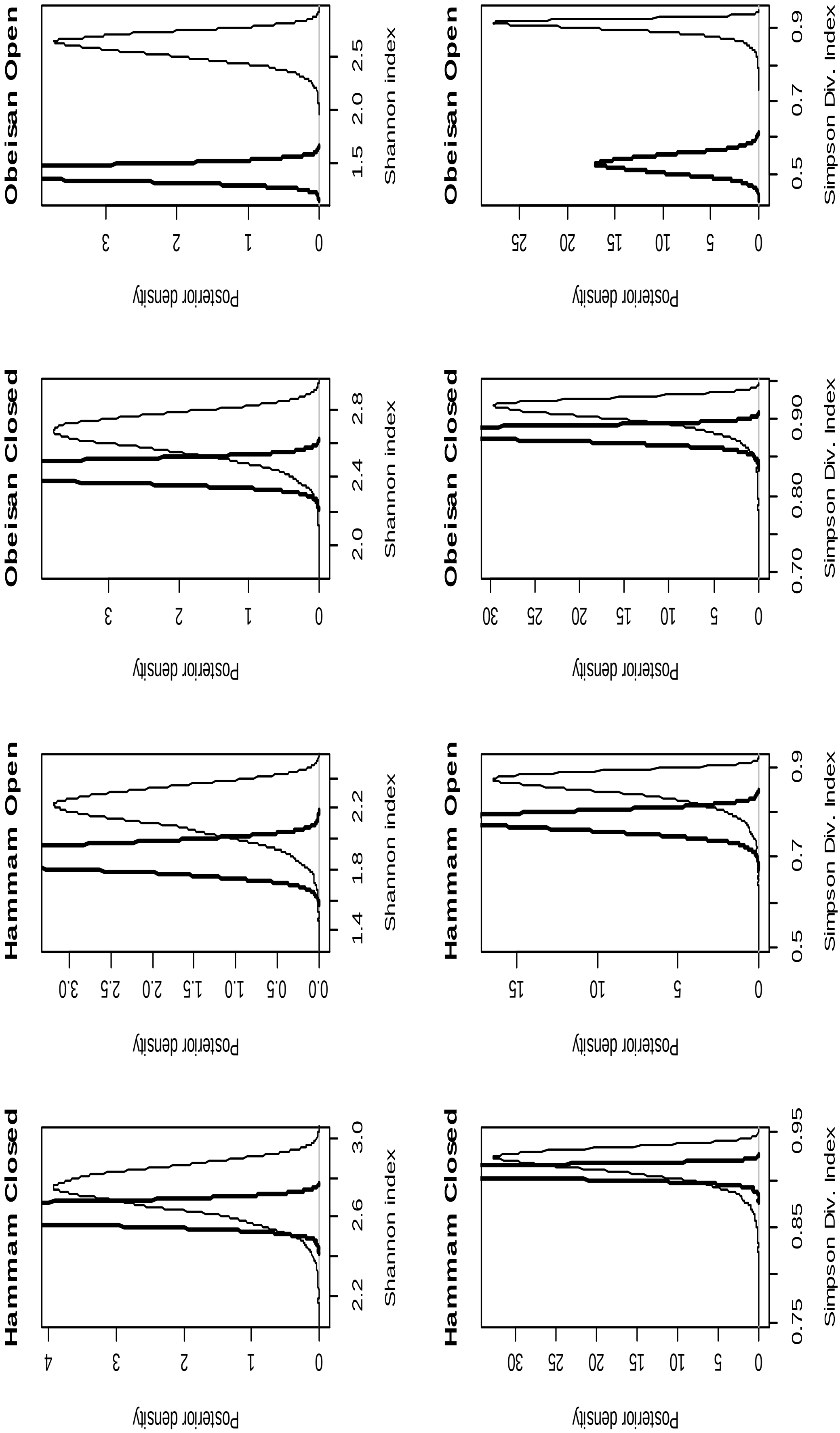

Fig. 4. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (equal)= 1

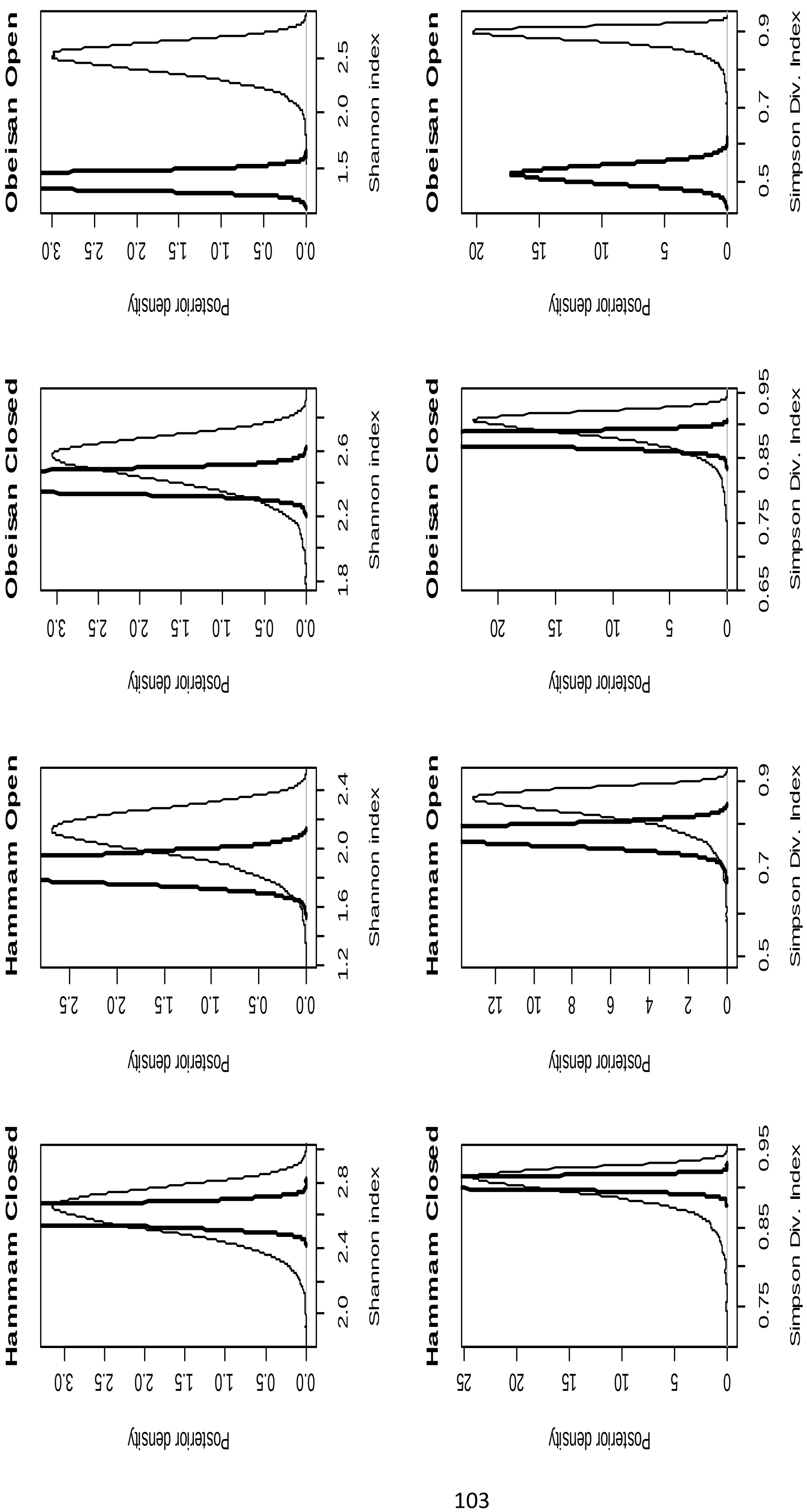

Fig. 5. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (unequal) generated as a random sample from uniform (0.5, k = 1)

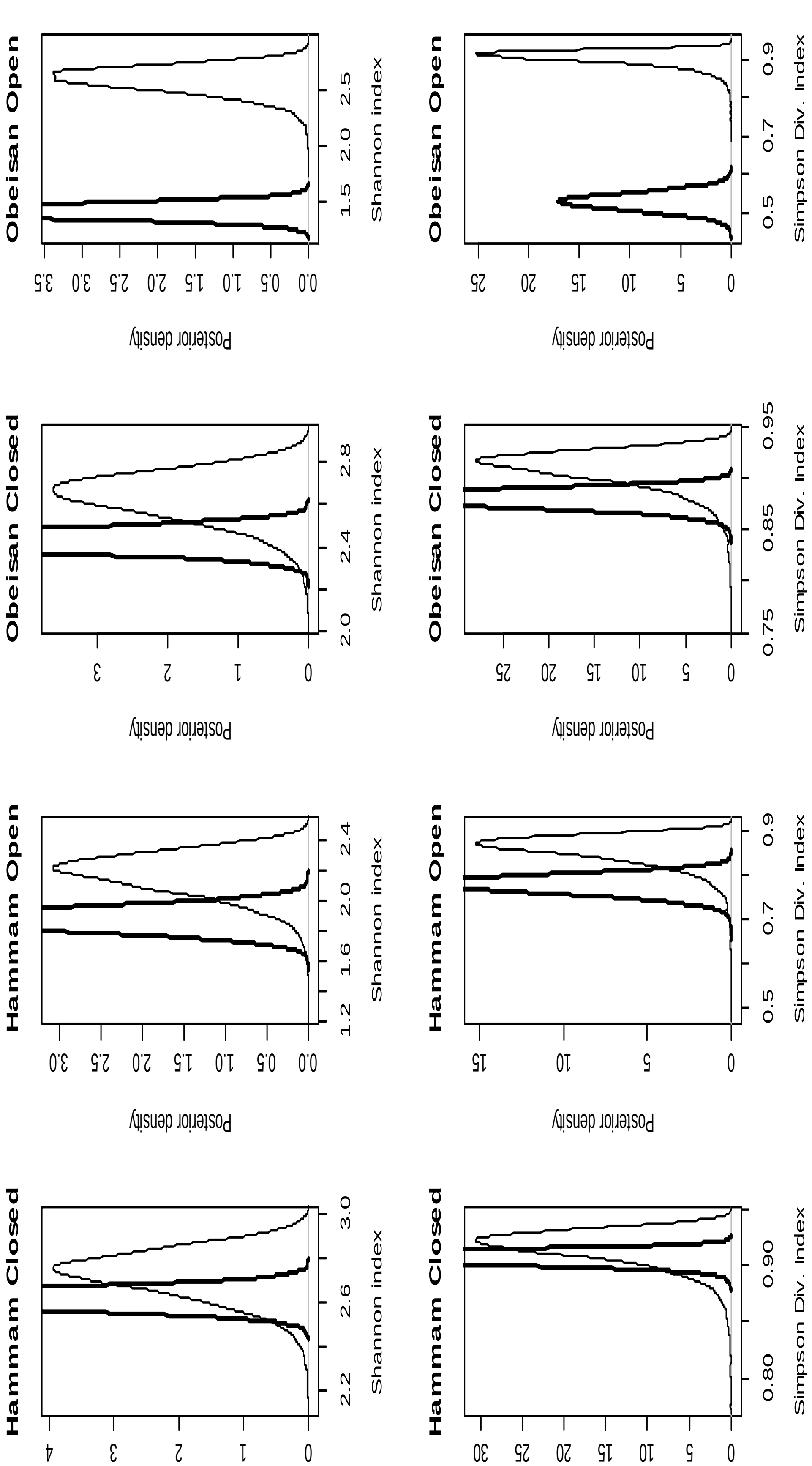

Fig. 6. Prior and posterior density of Shannon and Simpson indices for various flattening parameters α_i (unequal) generated as a random sample from geometric distribution and restricted in the range (lower = 1, upper = 3, r = 0.2)

4.2. Best prior/posterior

Since the H is a sum of random variables, the central limit theorem supports a normal approximation for its distribution for a large number of species classes. Each prior distribution results in a posterior distribution. To provide an estimate, a criterion is needed to select the most suitable distribution out of the posterior distributions considered for a given site and management combination. We took the sum of squares of skewness (γ_1) and kurtosis (γ_2) (SSSK) as a criterion, SSSK= $\gamma_1^2 + \gamma_2^2$. In case the SSSK is equal for any two posteriors, the preference was given to the low skewness model followed by a low kurtosis. Table 3 summarizes the Bayesian, selected using the SSSK criterion and frequentist estimates of the two diversity estimates for the site and grazing system combinations. Of the four cases, only for one case of Obeisan and Closed system, the same prior, i.e. α_i from Uniform (0.5, 1), was found most suitable for the estimation of H and SID indices. In each case, the Bayesian estimates of diversity were slightly higher than their frequentist counterparts and with lower standard error.

Table 3. Estimates and standard errors of diversity indices under frequentist and selected Bayesian models (H: Shannon index. SID: Simpson index of diversity. SE: standard error)

Site	Grazing	S	N	(α_i)*	Bayesian estimates		Frequentist estimates	
					H	SE	H	SE
Hammam	Closed	23	312	**Geometric**	**2.61**	**0.043**	2.56	0.045
Hammam	Open	13	171	**Uniform**	**1.86**	**0.075**	1.80	0.080
Obeisan	Closed	21	329	**Uniform**	**2.41**	**0.049**	2.38	0.050
Obeisan	Open	20	638	**Geometric**	**1.41**	**0.061**	1.33	0.061
					SID	SE	SID	SE
Hammam	Closed	23	312	**Fixed**	**0.91**	**0.005**	0.90	0.006
Hammam	Open	13	171	**Geometric**	**0.78**	**0.021**	0.76	0.023
Obeisan	Closed	21	329	**Uniform**	**0.88**	**0.008**	0.87	0.009
Obeisan	Open	20	638	**Uniform**	**0.52**	**0.023**	0.50	0.024

*: Parameters (α_i) generated using distribution

The two grazing management options were compared for diversity at each of the sites, and the sites were compared for each management using the indices estimated by the Bayesian and frequentist approach. To compare the two indices, we computed p-values based on the normal approximation of the difference of their estimates (Table 4). The two methods and the two sites show statistically significant differences at 1%, the commonly used level of significance. In most of the cases the p-values were extremely small. However, for the comparison of the two sites under no-grazing (closed), the p-values under the Bayesian approach were lower than those under the frequentist approach. This indicates that use of prior information can result in higher power for the comparisons.

Table 4. P-values for comparing the grazing methods and sites for the diversity (H: Shannon index. SID: Simpson index of diversity)

Comparison	within	H		SID	
		Frequentist	Bayesian	Frequentist	Bayesian
Closed vs. Open	Hammam	2.22E-16	<2.22E-16	1.08E-09	1.40E-09
Closed vs. Open	Obesian	<2.22E-16	<2.22E-16	<2.22E-16	<2.22E-16
Hammam vs. Obeisan	Closed	0.005792	0.0019225	0.0052731	0.002657
Hammam vs. Obeisan	Open	2.55E-06	0.0023331	3.33E-15	4.44E-16

5. Discussion

The Bayesian approach is a more general and realistic framework for drawing a statistical inference which utilizes the prior information about the parameters involved. With the availability of computing power, posterior distributions of parameters of interest can be obtained in general practice even when involving large number of nuisance parameters. This study examined the posterior distribution of two measures of diversity commonly used in practice. Choice of prior is an issue that would normally be subjective. However, if the prior distribution and posterior distribution overlap with high probability on axis of indices then it would be a desirable feature just like a conjugate prior is desirable in practise. If the probability of their overlap is very low then this indicates that our assumed prior is drifting too much away from reality. The sets of priors used in this study for proportion of species as parameters of Dirichlet distribution covered a wide range of distribution of diversity indices. The prior distribution of resulting diversity measures provided a reasonable envelope for the posterior distribution of the measures.

The selection of the best prior favoured those for which the resulting posterior distribution is close to normality. Since the indices are sums of random variables, their asymptotic distribution could be approximated by normal distribution. One way to examine an effective closeness to normal distribution is in terms of skewness and kurtosis, therefore, a combined index of skewness and kurtosis, as their sum of squares, was introduced. Other ways or methods of creating indices may be worthwhile.

Further, the diversity measures are based on the fact that the number of species was fixed and equal to the same as that which has been observed. There are methods which estimate the number of species using the sample data on the abundances of observed species (Good, 1953; Chou & Lee, 1992). Therefore, it would be more realistic to allow for random distribution of not only the proportion or abundance of a given species, but also of the number of species in a given geographical region during a given period of time.

6. Conclusion

A number of priors for the proportion of species were used in obtaining the Bayesian estimates and confidence interval of the two diversity indices. The Bayesian estimates of the diversity were larger, with smaller standard errors, compared to the estimates based on the frequentist approach which ignores any prior information. Significant differences were observed between the diversities of the two sites under each system of grazing management, and also between the two grazing managements at each site. At least in two comparisons, the Bayesian approach resulted in lower p-values. It is recommended that the use of the Bayesian approach be exploited in the estimation of diversity.

Acknowledgements
Authors thank Drs Mounir Louhaichi and Abdallah Bari, ICARDA for their helpful suggestions on an earlier version of the manuscript.

Chapter 5

Effects of temperature, relative humidity and moisture content on seed longevity of shrubby Russian Thistle *Salsola vermiculata* L.

This chapter has been accepted and presented for oral presentation in the 30th ISTA International Seed Symposium held from 12 to 14 June 2013 at Antalya, Turkey.

The manuscript is also accepted as a full length research paper in the *Journal of Agricultural Science and Technology*

Effects of temperature, relative humidity and moisture content on seed longevity of shrubby Russian Thistle *Salsola vermiculata* L.

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Chapter 5. Effects of temperature, relative humidity and moisture content on seed longevity of shrubby Russian thistle (Salsola vermiculata L.)

Abstract

Salsola vermiculata is a highly palatable shrub and widely used in rangeland rehabilitation programs, but has short seed longevity. To identify the most cost effective storage method for S. vermiculata, experiments were carried out to test the effects of fruit bracts (wings), temperature regimes, seed moisture, and packaging methods on storage life. Seed samples were removed from storage at monthly intervals for testing; and towards the end of the experiments samples were transferred from hermetic to ambient storage conditions and tested for germination. Experiment 1 continued for 1140 days compared with 720 for Experiment 2. For de-winged seed, high moisture content increased seed longevity, suggesting that desiccation susceptibility is one of the causes of limited longevity in this species. Most longevity regression lines of winged seeds had negative intercepts suggesting increase in germination resulting from gradual dormancy-breaking. Drying and packaging alone increased longevity by 7.6 and 3.8 times in Experiments 1 and 2, respectively. Samples kept at lower temperature and lower moisture treatments survived longer under ambient conditions. Increased longevity by drying and vacuum packaging alone can provide simple, cost effective and environmentally friendly options for rangeland rehabilitation programs.

Keywords: Salsola vermiculata L., seed storage, vacuum packaging, seed longevity, probit analysis

1. Introduction

Rangeland degradation is taking place at alarming rates in arid Mediterranean rangelands (Gallacher & Hill, 2006; Gintzburger et al., 2005; Le Houerou, 1981). Severe depletion of soil seed banks associated with rangeland degradation limits self-regeneration, thus necessitating reseeding (Tessema et al., 2012). The seed required for rehabilitation is usually collected from wild plants of the target species growing in less degraded areas of the rangelands. Due to temporal and spatial erratic rainfall distribution in arid Mediterranean rangelands (Sidahmed, 1996; Le Houerou, 1996), the required quantities of high quality seed cannot be harvested every year. To mitigate seed shortage in drought years, to maintain seed stocks for use in range nurseries, and for distribution to local communities, large seed stocks are collected in seasons with an abundant harvest. These stocks are stored under ambient conditions for long periods. In most rangeland rehabilitation programs in West Asia and North Africa, shrub seed stocks are kept in simple storage structures to minimize cost. This makes seed storability under ambient storage conditions critical for rangeland rehabilitation through reseeding.

Rangeland rehabilitation programs in West Asia and North Africa (WANA), including Syria, rely heavily on Chenopodiaceae species, especially *Atriplex* spp. and *Salsola vermiculata* L. (Mounir Louhaichi, 2011; Nefzaoui et al., 2011; Rae et al., 2001). However, research on the physical and physiological seed quality attributes and propagation methods for shrubs of the arid Mediterranean basin is limited (Baskin, 2003). Research on Saltbush (*Atriplex halimus* L.), showed significant variation in seed quality amongst seeds from different individual shrubs (Von Holdt, 1996). Three categories of seed with different germination rates could be differentiated.

The shrubby Russian thistle (*Salsola vermiculata* L.) is a major species in the Syrian rangeland flora and rehabilitation programs (Mourad et al., 2000). It is a native species with high ecological and forage value found distributed throughout the arid, semi-arid, saline and hyper-saline ecosystems of temperate and subtropical regions (Guma et al., 2010; Wen et al., 2010). It has a high success rate of establishment when self-sown, direct seeded or transplanted. It is easily propagated from seed and produces high quality biomass for feed and good seed yield for direct sowing under a wide range of rangeland conditions in WANA region (Osman et al., 2006). However, seed of *S. vermiculata* loses its viability within 6-9 months under ambient storage conditions (Osman & Ghassali, 1997; Tadros, 2000).

Effects of storage time, moisture and temperature on seed longevity have been investigated and reported for many crops and wild plant species. Based on their desiccation tolerance, seeds are classified as ’orthodox’ and ‘recalcitrant’ (Ellis, 1991).

The 'orthodox' seeds include a wide range of annual species (King & Roberts, 1979) for which 'Harrington's Rule of thumb' applies (Harrington, 1972). The term recalcitrant refers to those species for which Harrington's Rule does not apply because desiccation results in rapid loss of seed viability.

For *S. vermiculata*, research findings have already shown that by reducing storage temperature, seed longevity is significantly extended (Zaman et al., 2010; Osman & Ghassali, 1997). However, the effect of controlling seed moisture on storage has not been properly investigated. Therefore, this study was intended to investigate the combined effects of storage temperature and seed moisture on *S. vermiculata* seed longevity in order to determine the most cost-effective storage conditions for use in arid rangeland rehabilitation.

2. Materials and methods

2.1. Test material

Mature seed from Syrian ecotypes of *Salsola vermiculata* L. was collected in October 2002 and 2003 from the ICARDA rangeland nursery site located in north of Syria at 36°01'N, 36°56'E and 284 m above sea level. The seed stocks were cleaned and then subdivided into two parts, and dried to different moisture contents and stored for 1140 days (38 months) in Experiment 1 and 720 days (24 months) in Experiment 2. One part of seed stock was dried to low moisture content of 7% and 6.5% in Experiments 1 and 2, respectively by storing the seed for six weeks in a dehumidification room set at 16 °C and 18-22% relative humidity. The other part was kept at its harvest moisture content level of 10.7% and 9.6% in Experiments 1 and 2. Then the two batches of seed were subdivided into two parts. One part was de-winged using a Westrup La-h brushing machine (http://westrup.com/Products-Seed-and-Grain/Laboratory-equipment/LA-H) and the other part was left with wings intact in its natural condition. De-winging was done to break dormancy by eliminating the germination inhibitors accumulated in the wings (Osman & Ghassali, 1997). These different batches were stored in normal paper envelopes in non-vacuum sealed polythene bags or in sealed vacuum packages prepared using a chamber type vacuum packaging machine equipped with air extraction and heat sealing facilities at ICARDA gene bank. The steps described above resulted in eight batches of seed, namely non-dried and dried batches of winged and de-winged seeds in vacuum-sealed or paper packaging in sealed polythene bags.

2.2. Statistical design and set-up

In both Experiments 1 and 2, a completely randomized factorial design with four treatments: seed type (winged vs de-winged), three combinations of seed moisture content (MC) and packaging combined with three storage temperatures and time of storage. The treatment levels were winged or de-winged seeds; high MC with vacuum packaging, high initial MC without vacuum packaging, and low MC with vacuum packaging; the storage temperatures were -21 °C, 4 °C or 24 °C. Low initial MC could not have been maintained without vacuum packaging, neither high MC could have been maintained under non vacuum packaging. In both Experiments 1 and 2 there were two replications and samples were removed at regular intervals for testing. In each of the three storage temperatures, 288 seed samples were stored, representing two replications of six treatment combinations and 24 sample withdrawal with 50 seeds per experimental unit. In the second experiment, extra seed packages were stored for 720 days, then, transferred to non-vacuum polyethylene bags, kept at 24 °C and then tested at one month intervals for a period of 4 months to assess the seed longevity after hermetic storage.

In Experiment 1, the sampling interval was one month for the first 18 months and 4 months for the last 20 months. However, the data of the 7th and 8th months for the winged seeds were removed because of incubator breakdown. In Experiment 2 the sampling interval was one month throughout the period.

2.3. Seed testing procedures

Each month, a total of 12 envelopes, representing two replicates of the six treatment combinations were drawn from each of the three temperature regimes and tested for germination according to the International Seed Testing Association rules (ISTA, 2002). Petri dishes of 9 cm diameter with two layers of Whatman No. 41 filter paper were used in the germination tests. For each treatment combination, two replicates of 50 seeds were planted and placed in a germination chamber set at 20 ±2 °C and light (8 h; fluorescent light of 4.22 W m^{-2}) - dark (16 h) regime. The samples were watered every two days for a period of 10 days and germination was then assessed. The petri dishes were kept in the germination room for up to 20 days after evaluation but no additional germination was observed.

2.4. Statistical analysis

Analysis of variance was carried out to evaluate the significance of the main treatment effects and the interactions between them. The means and their standard errors were computed using Genstat statistical package (Payne et al., 2011). The restricted maximum likelihood (REML) procedure was used to test the significance of main effects and interactions of the treatment factors and to estimate the standard errors of the means. Instead of simple analysis of variance, REML facilitated to model the unbalanced design arising from the fact that seed could not be maintained at low moisture content without vacuum packaging and that zero germination percentages were recorded in the high moisture, paper-packaged seeds.

Regression analysis was applied by plotting germination proportions (better known as standard deviation) against time of storage in days to quantify the effects of time on seed longevity. The time in days for seed viability to drop to 50% (known as P50) was estimated from the probit model.

3. Results

3.1. Longevity trends

The overall analysis of variance showed that all possible three-way interactions were statistically significant (P<0.01). To facilitate interpretation and simplify presentation, the high order interaction table of seed type, moisture and packaging combination, storage temperature and time was disaggregated into winged and de-winged treatments, each of which was then sub-divided into the three temperature regimes under which the seed was maintained during storage.

Mean germination percentages after one month storage of winged and de-winged seed were 51% and 93%, respectively in Experiment 1 and 27% and 96% for Experiment 2 in the same order. This shows a 42% and 69%, increase in initial germination as a result of wing removal in Experiment 1 and Experiment 2, respectively.

The trends of change in seed longevity for winged and de-winged seeds separately are presented in six graphs embedded within two figures representing treatments grouped by temperature regime within each experiment (Fig. 1 for winged and Fig. 2 for de-winged seeds). Regardless of the moisture content and packaging, both winged and de-winged seeds maintained their initial germination levels when stored at -21 and 4 °C throughout both experiments. However, at 24 °C, the trends showed different rates of decline depending on seed moisture content.

The mean germination proportions (GP) over the entire storage period are presented in Fig. 3 (Experiment 1) and Fig. 4 (Experiment 2). Within each temperature regime, the GP of winged seeds consistently and significantly (P<0.01) declined between the vacuum and non-vacuum packaged seeds and from low to high MC treatments. For de-winged seeds, GP was highest (P<0.01) under the higher compared to the lower MC seeds. When stored at 24 °C, the mean GP for non-vacuum packaged winged was higher compared to winged seeds in vacuum packages in Experiment 1.

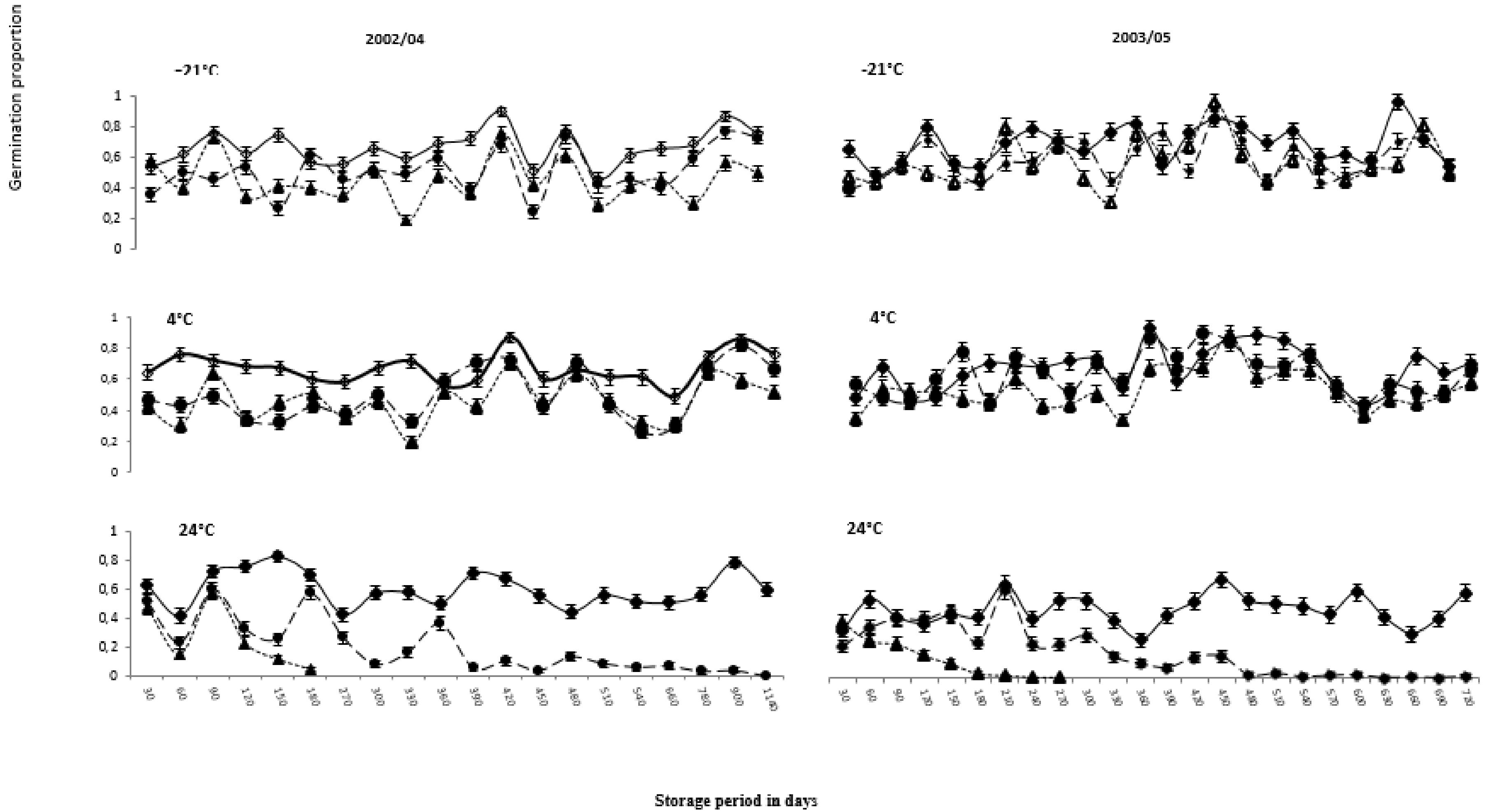

Figure 1: Proportion of germination of winged seeds of *Salsola vermiculata* L. with a moisture content (MC) of 7% and vacuum packaging (VP) (solid line with diamonds), with MC=10.7% and VP (dashed line with circles), and with MC=10.7% and no VP (dotted line with triangles) stored at -21, 4 and 24°C for 1140 and 720 days in 2002/04 (left panels) and 2003/05 (right panels), respectively. Note that the scales are not equidistant at the higher end of the x-axes.

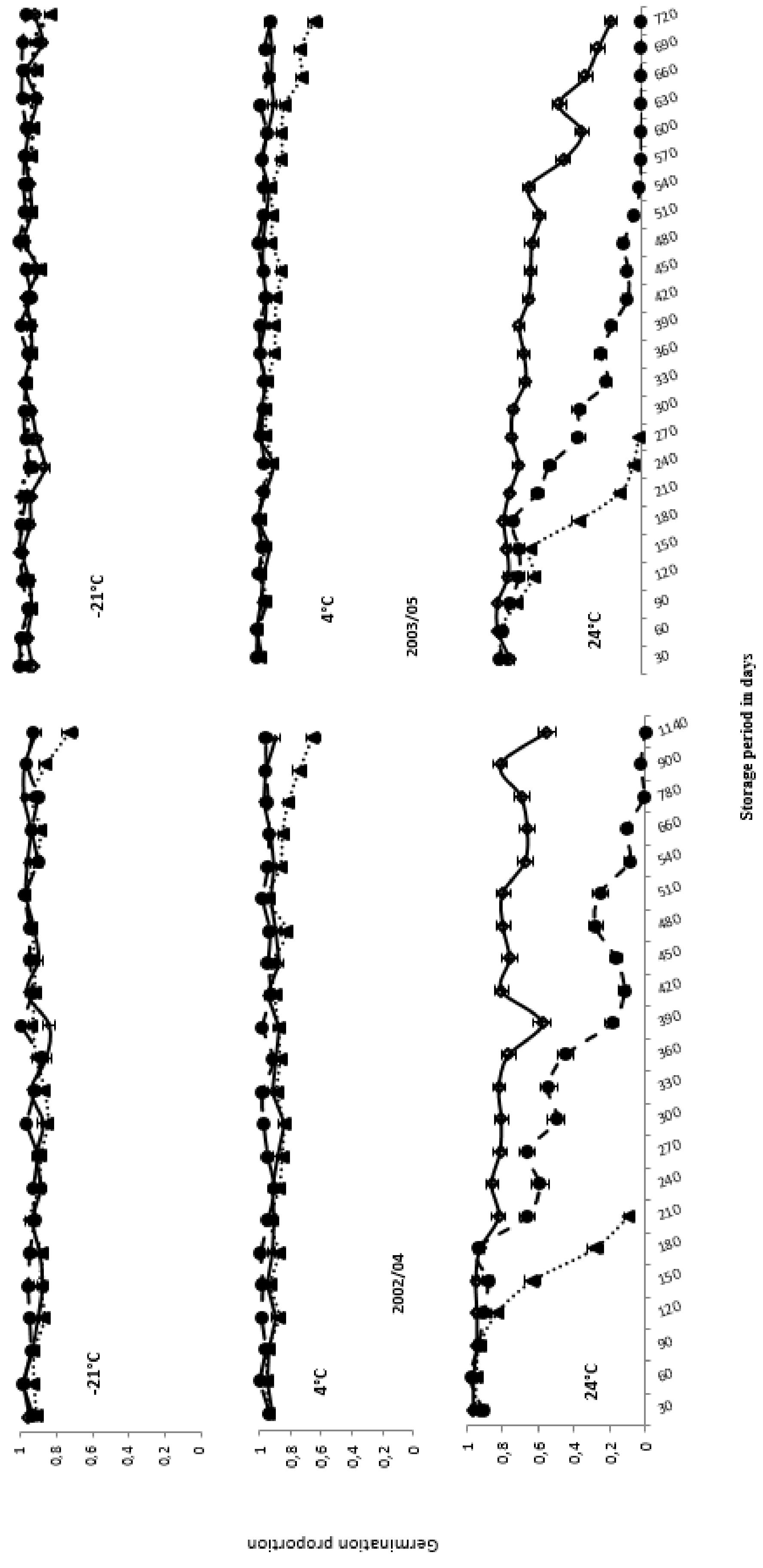

Figure 2: Proportion of germination of de-winged seeds of *Salsola vermiculata* L. with a moisture content (MC) of 7% and vacuum packaging (VP) (solid line with diamonds), with MC=10.7% and VP (dashed line with circles), and with MC=10.7% and no VP (dotted line with triangles) stored at -21, 4 and 24 °C for 1140 and 720 days in 2002/04 (left panels) and 2003/05 (right panels), respectively. Note that the scales are not equidistant at the higher end of the x-axes.

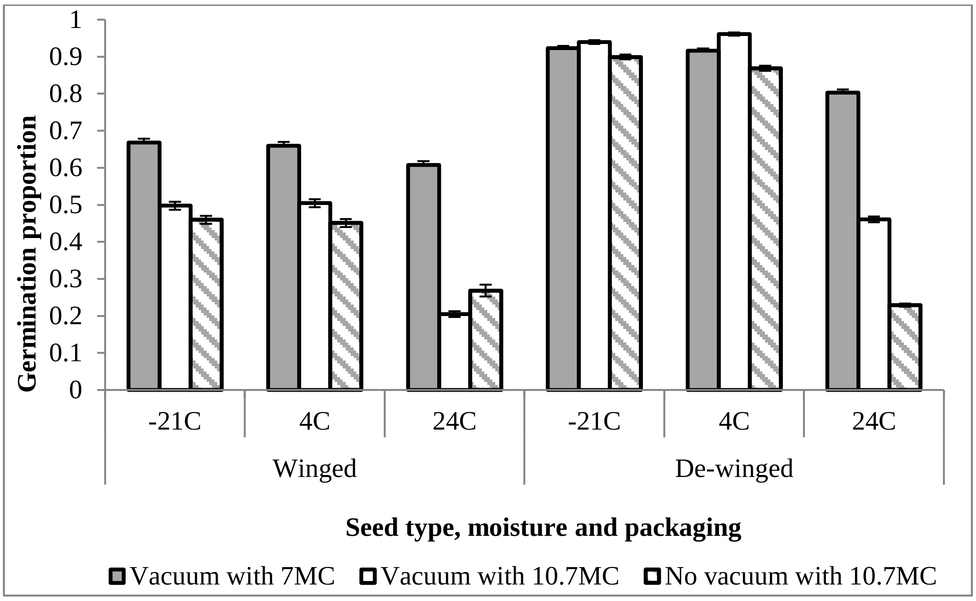

Figure 3: Mean predicted germination proportions with standard error bars for winged and de-winged seed of *Salsola vermiculata* L. with low (7 MC) and high (10.7MC) moisture content and vacuum and no-vacuum packaging stored at three temperature regimes for 1140 days (Experiment 1).

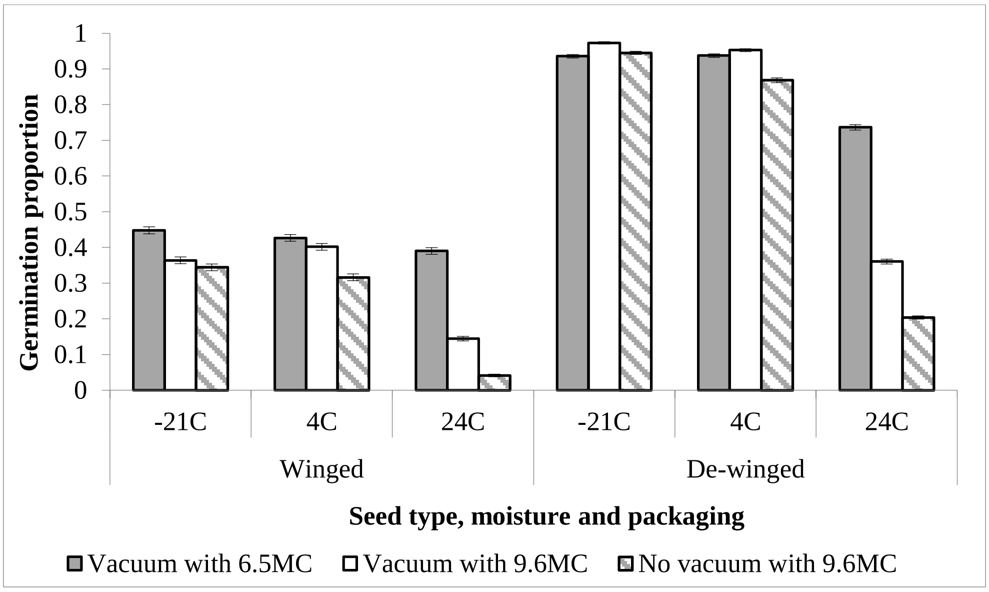

Figure 4: Mean predicted germination proportions with standard error bars for winged and de-winged seed of *Salsola vermiculata* L. with low (6.5MC) and high (9.6MC) moisture content and vacuum and no vacuum packaging stored at three temperature regimes for 720 days (Experiment 2).

3.2. Parameter estimates for longevity curves

Probit analyses results showed that for winged seeds the slopes were positive at -21 °C and 4 °C. The intercepts expressed in probit units were either negative or very low when positive. The decline in the P50s expressed in seed germinability gradient and slopes of regression with storage period did not follow the opposite direction of change in MC. For de-winged seeds, all regression line intercepts were positive and higher compared with the winged seeds. The decline in longevity was irregular along the seed moisture gradient under -21 °C and 4 °C for both winged and de-winged seeds and the seed longevity was highest under low MC with vacuum packaging followed by seed with high MC with vacuum then the high MC with no vacuum packaging (Tables 1 and 2). Moreover, for de-winged seeds stored at 4 °C and 24 °C, the regression coefficients, intercepts and correlation coefficients were all significant (P<0.01).

Results of the probit analyses also showed that in the control (non-vacuum packaging with MC of 10.7% in Exp. 1 or 9.6% in Exp. 2), lowering the storage temperature from 24 to 4°C resulted in an increase of P50 from 156 to 1651 days in Exp. 1 from 161 to 929 days in Exp. 2. The increases in P50 in the Experiments 1 and 2, respectively were 10.6 and 5.6 fold. When stored in vacuum packaging at 24°C, lowering the MC from 10.7% to 7% in Exp. 1 resulted in an increase of P50 from 322 to 1179 while MC reduction from 9.6% to 6.5% in Exp. 2 increased the P50 from 274 to 610. The increases in P50 in the experiments 1 and were in the same order, and of the magnitude of 3.7 and 2.2 fold, respectively. The increases in P50 resulting from drying and packaging alone were from 156 to 1179 in Exp. 1 and from 161 to 610 in Exp. 2. These results correspond to 7.6 and 3.8 fold increases in P50 (Fig. 5). When stored at high temperatures and high MC, P50 was consistently higher for vacuum compared to non-vacuum packaged seed but this was only significant in Exp. 2. The P50 values were significantly (P<0.01) higher in Exp. 1 than in Exp. 2. Moreover, all intercepts of the regression lines were positive, and significantly different from zero.

In addition to the trends of change in seed longevity shown in Figs 1, 2, 3 and 4, the results of the probit analyses performed on the individual sets of data representing regression of germination proportions against days of storage at 24°C are presented in Fig5. Fig 5 components showed significant decline in seed viability to zero within a 6, 10 and 23 months period of storage under 24°C with high MC% with and without vacuum packaging and low MC% with vacuum packaging, respectively.

Table 1: Parameter estimates for winged seed longevity curves of two seed lots of *Salsola vermiculata* L. under different storage conditions in 2002/04 and 2003/05

Year	T (°C)	MC%	Packaging	Gradient(1/δ)	P50 (days)	Intercept (probit)	Slope
1	-21	7	Vacuum	0.00061	1665 ±*	0.5±0.1	0.0003±0.0002ns
		10.7	Vacuum	0.00244	410.3 ±7	-0.2±0.05	0.001±0.0001***
			No vacuum	0.00131	766.2 ±774	-0.2±0.05	0.0003±0.0001**
	4	7	Vacuum	-0.00108	-930.1 ±1464	0.3±0.05	0.0003±0.0001**
		10.7	Vacuum	0.00277	361.1 ±62.2	-0.2±0.05	0.0006±0.0001***
			No vacuum	-0.0008	-1246 ±*	-0.1±0.05	-0.0001±0.0001***
	24	7	Vacuum	0.00083	1203 ±1170	0.3±0.05	-0.0003±0.0001***
		10.7	Vacuum	0.08621	11.9 ±21.6	0.04±0.07	-0.003±0.0002***
			No vacuum	0.02849	35.1 ±7.9	0.4±0.1	-0.01±0.001***
2	-21	6.5	Vacuum	0.00137	729.8 ±236	-0.3±0.05	0.0004±0.0001***
		9.6	Vacuum	0.00068	1481 ±1160	-0.5±0.05	0.0003±0.0001***
			No vacuum	0.00053	1877 ±5365	-0.5±0.06	0.0003±0.0001**
	4	6.5	Vacuum	0.00089	1120 ±8802	-0.3±0.05	0.0003±0.0001**
		9.6	Vacuum	0.00025	4031 ±*	-0.3±0.05	0.0001±0.0001ns
			No vacuum	0.00061	1640 ±776.9	-0.6±0.06	0.0004±0.0001***
	24	6.5	Vacuum	0.00045	2211 ±*	-0.3±0.05	0.0002±0.0001ns
		9.6	Vacuum	-0.02915	-34.3 ±22.1	-0.1±0.06ns	-0.003±0.0002***
			No vacuum	-0.05244	-19.1 ±14.9	-0.2±0.1	-0.009±0.001***

The gradient is the inverse of the longevity curve variance (δ) calculated here at P50 in days; ***: significant at $p>0.01$; Letters in front of figures indicate significant differences between treatments; ns: non-significant; the * sign for SE shows non converging iteration due to deviation from the standard life curve

Table 2: Parameter estimates for de-winged seed longevity curves of two seed lots of *Salsola vermiculata* L. stored under different storage conditions in 2002/04 and 2003/05

Year	T (°C)	MC%	Packaging	Gradient(1/δ)	P50 (days)	Intercept (probit)	Slope
1	-21	7	Vacuum	0.00033	3007 ±1065	1.5±0.07	-0.0005±0.0001***
		10.7	Vacuum	0.00011	8740 ±*	1.6±0.1	-0.0002±0.0002ns
			No vacuum	-0.00007	18621 ±*	1.4±0.07	-0.0001±0.0002ns
	4	7	Vacuum	0.00011	8747 ±*	1.4±0.07	-0.0002±0.0002ns
		10.7	Vacuum	0.00002	44069 ±*	1.7±0.09	-0.00004±0.0002ns
			No vacuum	0.00058	1738 ±222.5	1.5±0.06	-0.0009±0.0001***
	24	7	Vacuum	0.00096	1040 ±66.2	1.4±0.06	-0.001±0.0001***
		10.7	Vacuum	0.00311	321.5 ±5.7	1.9±0.08	-0.006±0.0002***
			No vacuum	0.0065	153.8 ±2.9	3.2±0.20	-0.02±0.001***
2	-21	6.5	Vacuum	0.0002	5075 ±*	1.7±0.09	-0.0003±0.0002ns
		9.6	Vacuum	0.00014	7190 ±*	2.0±0.1	-0.0003±0.0003ns
			No vacuum	0.0004	2491 ±2	1.9±0.1	-0.0008±0.0002***
	4	6.5	Vacuum	0.00028	3562 ±3419	1.7±0.1	-0.0005±0.0002***
		9.6	Vacuum	0.00033	3041 ±1616	1.9±0.1	-0.0006±0.0002***
			No vacuum	0.00108	929.2 ±43.9	2.0±0.1	-0.002±0.0002***
	24	6.5	Vacuum	0.00164	610.4 ±12.5	2.0±0.08	-0.003±0.0002***
		9.6	Vacuum	0.00365	274.2 ±4.9	2.0±0.09	-0.007±0.0003***
			No vacuum	0.0062	161.4 ±3.4	2.6±0.2	-0.02±0.001***

The gradient is the inverse of the longevity curve variance (δ) calculated here at P50 in days; ***: significant at p>0.01; Letters in front of figures indicate significant differences between treatments; ns: non-significant; the * sign for SE shows non converging iteration due to deviation from the standard life curve

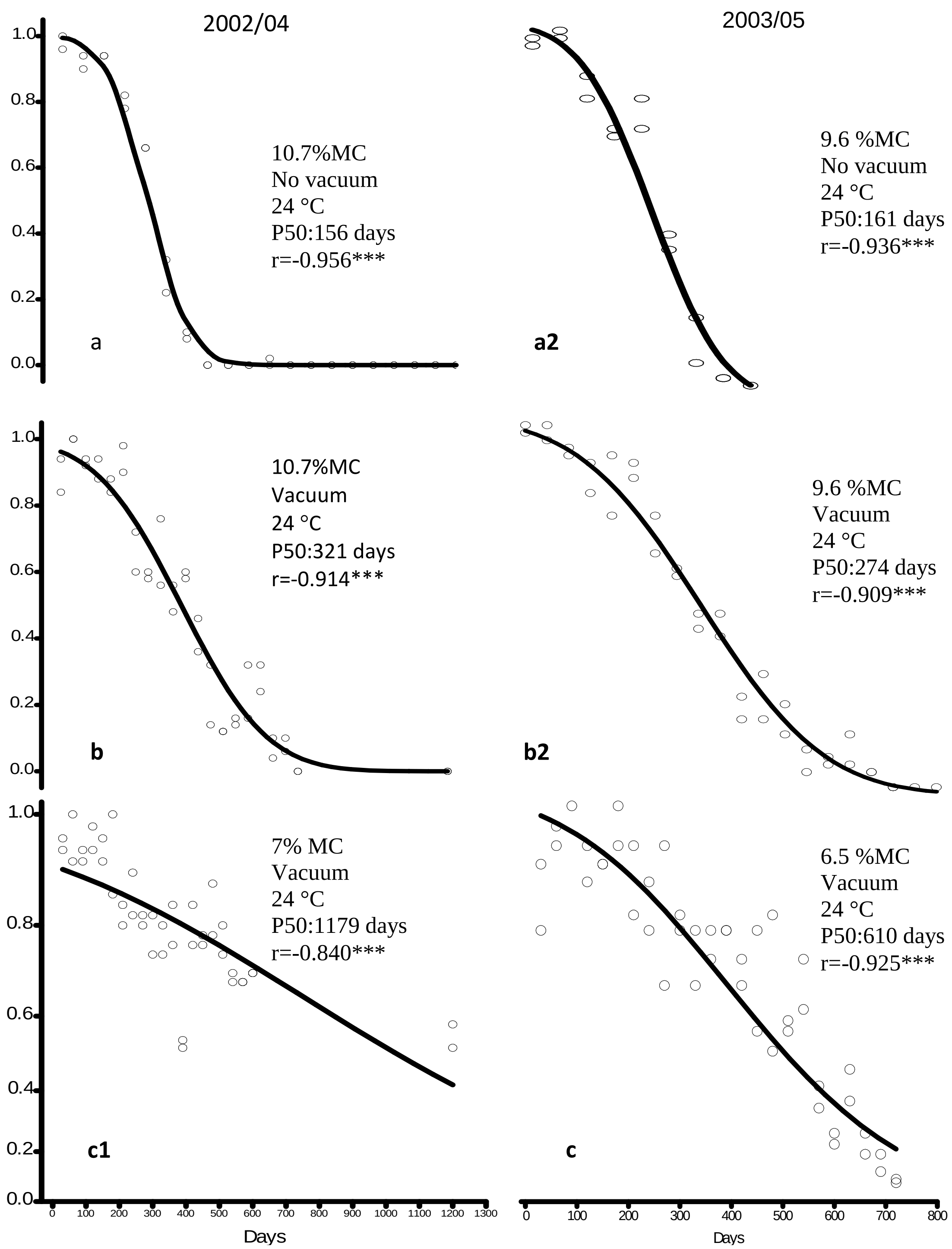

Figure 5: Seed longevity curves for germination proportion with days of storage for *Salsola vermiculata* L. (a1&a2= 24 °C, without vacuum packaging (WVP) and 10.7% moisture content (MC) for Exps 1 and 2; b1&2 = 24 °C, VP and 10.7%MC for Exps 1 and 2; c1&2 = 24 °C, (VP) and 7%MC for Exps 1 and 2

3.3. Post-hermetic storage longevity

In Experiment 2, the seeds transferred from vacuum and non-vacuum packages stored at -21 °C, 4 °C and 24 °C to ambient conditions showed slopes, intercepts and coefficients of determination for the regression lines which were all significant at P<0.01 (Table 3). Probit analysis on germination proportions with days of storage for seed transferred from hermetic to non-hermetic storage conditions showed that differences in P50 between treatments were significant for winged but not for de-winged seed. For de-winged seeds, differences in P50s were significantly different between vacuum and non-vacuum and among the temperature regimes. For non-vacuum packaging with fixed stable MC, the lower the temperature the higher the P50 became (Table 3).

The estimated number of days for a 50% drop in seed germination (P50) was consistently higher for the seed transferred from lower compared to those from higher temperature storage.

Table 3: Parameter estimates for winged and de-winged seed longevity curves of *S. vermiculata* L. transferred to ambient conditions after 720 days of hermetic and non-hermetic storage

Seed type	T °C	MC%	Packaging	Intercept (Probit)	Slope (degree)	P50 (days)*
Winged	-21	6.5	Vacuum	-0.1±0.2[ns]	-0.01±0.002[***]	-6±23.7[a]
		9.6	Vacuum	-0.3±0.2[ns]	-0.01±0.002[***]	-48±69.0[a]
			No vacuum	-0.7±0.2[***]	-0.01±0.003[***]	-89±95.7[a]
	4	6.5	Vacuum	-0.2±0.2[ns]	-0.01±0.002[***]	-20±29.5[a]
		9.6	Vacuum	0.1±0.2[ns]	-0.01±0.002[***]	4±13.7[a]
			No vacuum	-0.8±0.2[***]	-0.01±0.003[***]	-96±103.1[a]
	24	6.5	Vacuum	-0.1±0.2[ns]	-0.01±0.003[***]	-7±16.5[a]
De-winged	-21	6.5	Vacuum	1.5±0.2[***]	-0.02±0.002[***]	71±3.4[a]
		9.6	Vacuum	1.8±0.3[***]	-0.03±0.002[***]	71±2.9[a]
			No vacuum	0.8±0.2[***]	-0.02±0.002[***]	48±5.4[c]
	4	6.5	Vacuum	1.3±0.2[***]	-0.02±0.002[***]	65±3.7[ab]
		9.6	Vacuum	1.4±0.2[***]	-0.02±0.002[***]	59±3.2[b]
			No vacuum	0.9±0.2[***]	-0.02±0.002[***]	36±4.5[d]
	24	6.5	Vacuum	0.1±0.2[***]	-0.02±0.003[***]	6±10.2[e]

***: significant at P≤0.001; ns: non-significant; *: Different letters within seed type indicate significant difference in P50

4. Discussion

4.1. Longevity trends

Short seed longevity under high temperature and high MC and extended seed longevity under low temperature and low seed MC found from the two experiments on both winged and de-winged seeds is consistent with the well-established and widely-reported storage behavior for *S. vermiculata* (Guma et al., 2010; Zaman et al., 2010; Osman & Ghassali, 1997) and for other orthodox seed species (Ellis, 1991). Nonetheless, the previous studies on *Salsola* seed longevity focused on the effect of temperature, whereas the present study introduced the control of moisture content as a more cost-effective storage approach for rangeland management and rehabilitation.

4.2. Parameter estimates for longevity curves

The low and negative intercepts and P50 values with high standard errors recorded in the winged seeds are attributable to the confounded effects of simultaneous seed dormancy breaking and natural deterioration in viability due to aging. Loss of dormancy continuously generates new germinable seeds while natural deterioration in seed viability takes place within the seed populations harvested from the wild with high inherent variability clearly expressed in flower and fruit color. The cyclic trend of germination disappeared when fruit bract was removed as shown in the de-winged seed longevity trend graphs.

The large differences in germination percentages between winged and de-winged seeds recorded after one month of storage indicate a high level of dormancy in the winged seeds. The presence of germination inhibitors in *S. vermiculata* wings and their effects on germination have been reported (Osman & Ghassali, 1997). It seems that the rates of dormancy breaking and natural deterioration among the dormant and non-dormant seeds seem to be canceling out each other and maintaining the overall germination at its initial low level. Nonetheless, the negative intercepts of regressions of the germination proportions against days of storage indicate that the rate at which dormancy breaking is taking place seems to be slightly greater than the rate of deterioration in seed viability. The negative intercepts suggest an increase in seed longevity instead of decline. This increase implies that the regression line will intersect with the x-axis before its zero level. In other words, the model is estimating the number of days required for the seed viability to increase instead of dropping to 50%. Dormancy breaking and deterioration processes have been reported to be controlled by temperature ranging from -10°C to 70 °C (Roberts, 1988). The experiments were conducted within this range of temperatures.

The higher seed longevity of vacuum packaged seeds with higher MC compared to lower and similar seed moisture content with and without vacuum packing is probably due to desiccation damage in the low MC treatment and higher respiration rate in the non-vacuum packaged seeds (Figs 3 and 4). Reduced seed longevity under lower moisture content found in this study is not in line with the reported negative logarithmic relationship of seed longevity with moisture content (Ellis & Hong, 2006). Ellis (1991) reported upper and lower limits for this negative relationship, although these limits vary among the orthodox species. Beyond the limits, further reduction in seed moisture does not increase or decrease seed longevity. Nevertheless, the moisture and temperature treatments under which change in seed longevity did not match the expected negative relationship falls within the operational boundaries of the negative relationship which is -20 °C to 75 °C (Ellis, 1991). Ellis & Hong (2006) cited that desiccation below the optimum moisture content greatly increases seed storage deterioration. Low germination in drier compared to more moist seed has been reported in sorghum (Phillips & Youngman, 1971).

The reduced longevity under lower moisture content could also be attributed to interdependence of temperature and moisture effects on longevity or to desiccation damage. Vertucci et al. (1994) found that optimum storage moisture content cannot be considered independently of temperature. It seems that the temperature at which longevity was reduced was not optimum for the level of seed moisture content to which the seed was dried. In a study on desiccation-induced damage in orthodox seeds, Leprince et al. (1995) concluded that the expression of desiccation damage depends on the drying history and that factors that limit metabolism also reduce the incidence of desiccation injury. The improved seed longevity in the seed with higher moisture content suggests that the short storage life in *S. vermiculata* seed is due to its sensitivity to desiccation. Seed moisture content above 6% is not considered too low for the desert environments in which *S. vermiculata* is widespread and endemic. In addition, the P50 value of 1651 days predicted for non-vacuum packaged seeds with 10.7% MC stored at 4 °C compared with a predicted P50 value of 1179 days for vacuum packaged seed with 7% MC stored at 24 °C indicates that *S. vermiculata* seed longevity is more dependent on temperature than moisture. Nevertheless, the actual and the theoretical longevity results from the present study suggest that *S. vermiculata* can be truly classified as an orthodox species. Ellis (1991) stated that seeds of some tropical crops show an intermediate category of seed storage behavior and it is not yet clear how many species belong to this category. The findings from the present study suggest that *S. vermiculata* could be a candidate for that intermediate category.

The significantly greater values for P50 in Exp. 1 compared to those in Exp. 2 are probably due to the fact that Exp. 1 continued for longer than Exp. 2. The 7.6 and 3.8 fold increase in P50 achieved in Exps. 1 and 2 respectively through drying and packaging has important practical and cost implications for rangeland rehabilitation. Increases in P50 from 156 to 1179 in Exp. 1 and from 161 to 610 in Exp. 2 are equivalent to an increase in storage life from less than six months to 3 years in Exp. 1 and to about 2 years in Exp. 2.

4.3. Post-hermetic storage longevity

For the seeds which were transferred from vacuum and non-vacuum packages to ambient conditions, the slopes, intercepts and correlation coefficients of determination for the regression lines were all significant at $P<0.01$ (Table 3). Probit analysis on germination proportion with days of storage for the seed without wings transferred from the vacuum and non-vacuum packaged seeds showed that differences in P50 were not significant between high and low moisture contents within the three storage temperature regimes. For non-vacuum packaging with fixed MC, the lower the storage temperature, the higher the P50 became (Table 3).

The estimated number of days for 50% decline in seed germination (P50) was consistently higher ($P<0.01$) under high MC and low temperatures compared to low MC and high temperatures. For seed stored at high temperatures and high MC, the P50 was higher for vacuum-packaged seed, but only significantly so in Exp. 2. For the de-winged seeds, the intercepts of the regression lines were all positive and significantly ($P<0.001$) different from zero, indicating a consistent decline in seed longevity with time.

The slower decline in germination of seed transferred from the lower temperature and moisture content treatment is probably due to the fact that deterioration was minimal in hermetic storage conditions. Roberts (1988) asserted that seeds continuously deteriorate at a rate that is mainly dependent on moisture content and temperature and, unless germinated, will ultimately die. The most important reasons for Ellis and Roberts to develop improved equation for predicting longevity was to reflect variations in lot history among crop species and genotypes (Ellis & Roberts, 1980).

5. Conclusions

The improved seed storage in the higher moisture content treatments found in the present study suggests that the short storage life in *S. vermiculata* observed in the field is attributable to sensitivity to desiccation. Special attention should be given to desiccation control in medium and long term storing seed of this species.

The negative intercepts of the regression lines of the winged seeds indicate that the seed dormancy resulting from germination inhibitors in the wings increases seed longevity.

The study clearly showed that drying and vacuum packaging alone resulted in a substantial increase in seed longevity. This finding is a significant step towards more cost-effective and environmentally friendly rangeland rehabilitation.

The reduced storage life of seed transferred from vacuum packaging under ambient conditions treatments to non-vacuum packaging needs to be taken into consideration. Such seed should be sown late when the probability of rainfall is high or used in the rangeland nurseries under irrigation.

Chapter 6

General discussion

Chapter 6. General discussion

1. Introduction

1.1. What are rangelands?

Rangelands are natural ecosystems extending across the six terrestrial biomes of the world, i.e. coniferous, deciduous, and tropical forests, desert, tundra and grassland (Han, 2007). They are covered with natural vegetation consisting of wild plant populations which are adapted to herbivory and incompatible with the extensive pasture and crop management based agronomic practices such as cultivation, sowing and harvesting. Rangelands are a habitat and source of feed for domestic and wild animals on which millions of people living on and from them depend for their livelihood.

Representing 55% and 75% of the world and the semi-arid to arid Mediterranean land areas, respectively, rangelands are significant for global and local environmental health, biodiversity repository and food security. The arid rangelands in the Mediterranean basin are degrading at alarming rates in terms of area, carrying capacity and biodiversity. The reasons are the expansion of urbanization and escalating attempts to manage and exploit them as pasture, cropland and productive forests (Sanlaville, 2003; Le Houerou, 1996).

In an attempt to stop and reverse the process of degradation, large-scale restoration programs have been implemented throughout the countries in the south Mediterranean basin and beyond, with varying rates of success. In most rehabilitation programs, the techniques of halophyte transplanting, reseeding combined with resting and rotational grazing were used. The programs succeeded in establishing good vegetation cover over vast areas in several countries including Morocco, Tunisia, Syria, Jordan, Portugal, Pakistan and Iran (Nefzaoui et al., 2011; Le Houerou, 2000; Aronson et al., 1993).

Nevertheless, the sustainability of the rehabilitation programs faces several challenges. Exponential increase in the domestic animal population, escalating expansion in urbanization, systematic destruction of the slowly renewable perennial vegetation cover through opportunistic cultivation resulting in soil and subsequent green cover depletion and biodiversity erosion are some of the challenges. Heavy traffic, trampling and wind, uprooting of shrubs for fire wood and amenity, inadequate rural development policies converting rangeland communities from nomadic into semi or fully sedentary lifestyles contribute to rangeland degradation (Louhaichi, 2011; ACSAD, 2004; Sanlaville, 2003).

1.2. Evolutionary grazing shaped-up Mediterranean rangelands

Based on mean annual precipitation Le Houerou (1981) classified the Mediterranean vegetation into arid, semi-arid and humid, each of which was then subdivided based on minimum temperature into five sub-categories, namely warm, mild, cool, cold and very cold winter. Defined as land on which wild and domesticated livestock wander for food (Catharinus & Thalen, 1979), the Mediterranean rangelands spatially extend across all five sub-categories. Temporally linked to the existence of herbivores on earth, they are among the regions with a long herbivory history (e.g. Africa, Mediterranean, and Andean South America). In those regions, the vegetation evolved with ungulates and/or similar large mammalian herbivores since at least the Pleistocene (ca. 10,000 years ago), including the presence of domestic or semi-domestic ungulates since at least ca. 4,000 years ago (Díaz et al., 2007).

1.3. Rangeland significance and degradation issues in Syria

The Syrian rangelands cover 10.2 million ha and represent 55% of the country's land area and 97.4% of the non-agricultural land (ACSAD, 2004; Sankary, 1977). Rangelands constitute an important source of livelihood for a significant part of the population, a cornerstone in the country's food security, environmental health and biodiversity repository. Rangelands are major sources of free feed for domesticated animals, natural habitat for wild life, amenities and tourism from all over the world. The percentage of rangeland contribution to ruminant feed supply in Syrian is estimated at about 40% (ACSAD, 2004; Mourad, 2000).

The average carrying capacity of the Syrian rangelands is estimated at 1.33 head ha^{-1} $year^{-1}$ (ACSAD, 2004). At this carrying capacity, the 10.2 million ha rangelands in Syria can sustain a maximum number of 13.6 million heads of sheep, which is about half of the current sheep population in the country. Under such circumstances, degradation becomes a reality rather than a possibility. Overgrazing, opportunistic cultivation, deforestation and overstocking are the major causes of arid rangeland degradation (Le Houerou, 1996).

1.4. General objective of the study

The underlying assumptions of the rehabilitation programs are that an established vegetation cover of phanerophytes and nanophanerophytes will halt loss of soil, moisture, nutrients, erosion of seed bank and will facilitate rebuilding of soil structure, accumulation of seed of annuals and perennial forbs and grasses and activate organic matter recycling and buildup of soil micro flora (Le Houerou, 2000) resulting in above and under ground cover recovery. The aim of the present study was to test the above hypothesis on the Syrian arid Mediterranean rangelands under a 50-years long rehabilitation program.

1.5. Specific objectives

The specific objectives of the study were to (1) study the impacts of resting, rotational and continuous grazing on vegetation cover and soil seed bank abundance, species richness and diversity in the arid Mediterranean type climate rangelands of Syria, (2) explore the Bayesian statistics approach for diversity estimation as compared with the frequentist methods, and (3) Investigate cost-effective storage methods for *Salsola vermiculata* L., a highly palatable, environmentally adapted and widely used species in rangeland rehabilitation programs in Syria and beyond.

2. Highlights from the study on impacts of rotational grazing on vegetation cover

2.1. Research questions

Grazing is widely recognized as a major driver of vegetation cover dynamics in grazing lands. The debate is about the mechanisms by which grazing shapes up plant communities in rangelands. This debate resulted in several hypotheses for which universality was claimed. Díaz et al. (2007) recognized that empirical tests of several hypotheses linking plant traits with grazing at regional and global level were lacking. They tested the consistency of the widely recognized models of responses of plant traits to grazing and concluded that classifications of plant functional types and response rules need to be specific to regions with different climate and herbivory history. This conclusion reflects the generalized grazing model developed by Milchunas et al. (1988). The model stipulates that selection pressures resulting from grazing and from environmental moisture through evolutionary time shaped the present composition and physiognomy of grasslands and their relative abilities to withstand grazing. Based on this model the mode and magnitude of grazing action and of the community reaction are functions of past history of the community. Nonetheless, the specific conclusions from the study of Díaz et al. (2007) in which grazing favored annual over perennial, short over tall, prostrate over erect, and stoloniferous and rosette over tussock architecture were broadly in line with the range-succession model (Dyksterhuis, 1949). The range-succession model predicts an increase in annual plant cover and a decrease of perennials with grazing, replacement of palatable plants by unpalatable ones, and replacement of tall and intermediate height grasses by short grasses, subshrubs, and perennial prostrate forbs. The only difference between the two models is that the former assumes that the reported pattern of grazing selection depends on precipitation and grazing history, whereas the latter assumes that the patterns are universal and unaffected by differences in the characteristics of different regions. This shows the overlapping and complementarity of different models.

This chapter of the present study aimed at investigating the ways in which the grazing management component of the rangeland rehabilitation programs is shaping up the vegetation cover of the arid Mediterranean grazing lands in light of the well-established herbivore-plant community dynamic models. In other words, the study was designed to generate evaluation and monitoring indicators based on quantitative data to validate the basic assumptions of the rehabilitation programs for a greater green cover integrity, diversity and productivity.

2.2. Methodology

Two well-established and contrasting data collection methods, i.e. quadrat and point intercept were used in the study. Data on vegetation cover abundance and composition were collected along a grazing gradient of ten rangeland rehabilitation sites in northern Syria. The data was collected at the peak of blooming in two consecutive seasons. Plant density, richness and diversity indices were generated from the floristic and functional groups of the plant communities along the grazing gradients of the ten sites and compared.

2.3. Major findings

Trends of change in plant community composition

A total of 121 taxa of 97 genera from 34 families were recorded in the vegetation cover study. The number of species captured by the quadrat and point intercept methods was similar. Results from ANOVA showed significant site-by-year and site-by-grazing interactions for density and richness, but not for diversity. However, pair-wise comparison of diversity indices showed that diversity was lowest under the driest season and under rotational grazing. Moreover, rotational grazing resulted in a significant increase in plant density of perennial grasses which is a major element of arid rangeland health and integrity. This suggests a positive relationship between abundance and diversity and a shift in species dominance from the high to the low proportional abundance types which is an indication of the shaping effects of herbivory on rangeland plant communities moderated by environmental conditions.

2.4. Synthesis

Resting and rotational grazing resulted in increased plant density and in plant community composition change arising from shift in dominance from the higher proportional abundance and more invasive species rich perennial forbs to its contrasting perennial grasses. These results suggest that, under arid Mediterranean rangelands, rotational grazing seems to optimize flora diversity through moderating plant community composition dynamics based on species facilitation and association mechanisms. The shaping-up effects of rotational grazing on arid rangeland plant communities found in this and other studies (Milchunas et al., 1988; Díaz et al., 2007), could form a reasonable ground for a triangle of overgrazing disturbance to plant community composition and functions, aiming at ecosystem disequilibrium monitoring and control, consisting of:

(1) favorable biophysical environment for plant community disturbance related to soil, nutrients, moisture, organic matter resulting from litter turnover in which microorganisms play a crucial role (Snyman & Preez, 2005);

(2) pressure of fauna, in particular the domestic and wild herbivores on plant community in terms of type, timing of access and rates of stocking; and

(3) the flora dynamics related to interference and facilitation and association with dominant herbivores in terms of levels and mechanisms of susceptibility and tolerance. The triangle could be the basis of an integrated approach to sustainable management and rehabilitation of Mediterranean arid rangelands (Fig. 1).

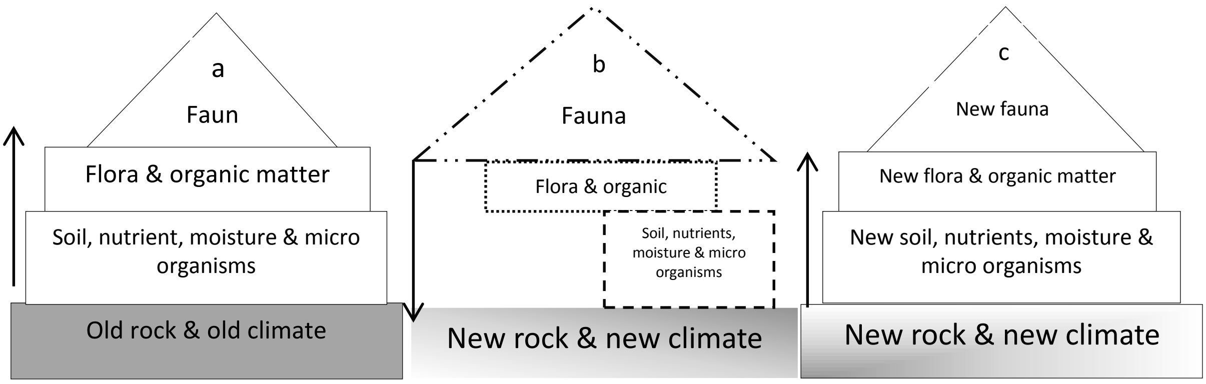

Figure 1: Rangeland ecosystem dynamics: (a) system at equilibrium, (b) non-equilibrium and (c) new equilibrium (different patterns of lines indicate change of communities and formations while arrows show general directions of system development).

There was a significant difference in plant density and high similarity in species diversity between full protection and continuous grazing compared to rotational grazing. This suggests that plant community composition has already been shaped-up by the historical evolutionary herbivory of the plant communities studied. The higher species richness and diversity under continuous grazing showed in the pair-wise comparison is in line with an early seral associated surge in species diversity (Ferrer-castán & Vetaas, 2003). The surge in species richness and diversity under continuous grazing is attributable to migration of plant propagules from adjacent areas and exploitation of the open spaces created by the significant decline in plant density in particular the geophytic perennials.

The significant site-by-season and site-by-grazing interactions for density and richness show the effects of spatial and temporal variability within and between the plant communities in the study area. The variations are attributable to the inherent edaphic, topographic and climatic variations in the arid Mediterranean rangelands. The patchiness of vegetation cover in the arid Mediterranean grasslands and its effect on diversity has been reported by other investigators (Kansur et al., 2010; Nooralhamad, 2006). Spatial and temporal habitat heterogeneity is important for maximizing and sustaining biodiversity (Fuhlendorf & Engle, 2001).

A plausible explanation for the higher plant density of annuals under full protection is the higher soil moisture and nutrient content resulting from the lower level of potential evaporation due to better vegetative cover and higher content and active recycling of organic matter. As the name indicates, the life cycle of annual plants depends on seasonal changes in soil moisture resulting from different forms of precipitation.

The dominance of the chamaephyte life forms under continuous grazing areas is probably due to their high grazing tolerance and wide spread poor palatability among them. The perennial forb group is dominated by poisonous and thorny nanophanerophytes such as *Peganum harmala* L. and *Noaea mucronata* (Forssk.) Asch. & Schweinf.

The higher plant density of geophytes under rotational grazing is in line with research reports on selective grazing favoring short, prostrate and stoloniferous plants over tall, erect and tussock types (Papanikolaou et al., 2011; Díaz et al., 2007). Stipa, which is a tall endemic and main component of the Syrian rangeland flora, is disappearing from the Syrian steppe. The lower proportional abundance resulting from the dominance of few geophyte and hemicryptophytes is probably the reason for the reduced species diversity under rotational grazing.

2.5. Conclusions

- The consistent and significant increases in overall plant density showed that rotational grazing is a viable option for arid Mediterranean rangeland rehabilitation with eminent economic as well as environmental health merits.
- The consistent and significant decline in plant density of annuals and perennial grasses under continuous overstocking shows that it is a major cause of degradation resulting in vegetation cover deterioration and subsequent biodiversity and soil erosion.
- The proliferation of thorny and poorly palatable nanophanerophytes exploiting gaps created by deterioration in perennial grass cover under continuous grazing

implies that invasive plant control should be considered in future rehabilitation programs.

- Generating comparable results with fewer efforts, the point intercept seems more efficient than the quadrat method of vegetation cover studies in arid Mediterranean rangelands.
- It is worthwhile to reiterating that artificial range or pasture reseeding is usually not feasible either technically or economically in the arid zone *sensu stricto*, unlike in the semi-arid and sub-humid zones. It would not do any good, anyway, unless the management of the range was improved and the causes of its deterioration discontinued (Le Houerou, 1996).

3. Highlights of impacts of rotational grazing on soil seed bank

The research questions for this section are in line with those of the vegetation cover study and arise from the overall rehabilitation assumptions.

3.1. Methodology

For this study, physical seed extraction and germinable soil seed bank testing methods were used. Data on soil seed bank size, floristic and plant functional group compositions were collected along a grazing gradient of ten rangeland rehabilitation sites in northern Syria. The data was collected at the peak of seed rain and primary dormancy breaking during autumn in two consecutive seasons. The data collected was computed to generate soil seed bank size, richness and diversity indices at floristic and functional group levels of the plant communities along the grazing gradients of the ten sites and compared.

3.2. Major findings

Trends of change in floristic and functional plant group soil seed bank composition

A total of 108 taxa from 93 genera and 48 families were recorded through physical seed extraction and germinable soil seed bank test methods. The flora components captured soil seed bank method were higher for germinable than physical soil seed bank method. However, germinable soil seed bank missed the phanerophytes due to wide spread mechanical dormancy among these species.

Results from ANOVA showed no significant differences in physical or germinable soil seed bank size between grazing treatments. However, there were significant site-by-grazing interactions for both and in year-by-site too for germinable soil seed bank size only.

There was simultaneous surge and decline in seed bank sizes of annuals and perennials under different grazing treatments and higher seed bank sizes of perennials then annuals under rotational grazing showing again the moderating mechanism of grazing on plant community dynamics. The change in plant community composition resulting from shift in dominance of species with different proportional abundance was also prominent in both soil seed bank analysis methods and high similarity indices, particularly for GSSB, with above ground vegetation measurements.

3.3. Synthesis

The significant interactions between site, year and grazing shown in the vegetation cover dynamics were reconfirmed for the physical and germinable soil seed bank. The interactions were more prominent for the germinable than for the physical soil seed bank. The reason is probably the higher coefficients of variation for PSSB resulting from the inherent differences in number of seeds produced by individual plants of different plant species under different edaphic, soil moisture stress and climatic conditions.

For the overall trends of change in soil seed bank diversity, GSSB matched those of vegetation cover more than PSSB. The justifications given for the trends of change in vegetation cover may be largely valid for those of GSSB. For the mismatch between PSSB richness and both vegetation cover and GSSB, a plausible explanation could be that the number of viable seeds in a species seed mixture was not proportionate to the total number of its physically identifiable seeds. Due to poor seed quality resulting from growing conditions or dormancy, the rate of germination varies within and between species. Sørensen and Morisita-Horn similarity tests showed low similarity indices between PSSB and each of GSSB and vegetation cover.

The trends of change in germinable soil seed bank of functional groups seems to be governed by the gap exploitation hypothesis stipulating that transient seed banks are adapted to exploit the gaps created by seasonally-predictable damage and mortality in the vegetation (Thompson & Grime, 1979). Under arid Mediterranean rangelands, annuals are of winter types and get natural after ripen treatment from the summer heat. Such annuals form the type of transient soil seed (Baskin & Baskin, 1988) that is necessary for gap exploitation. There seems to be a perfect synchronicity between declining perennials creating gaps with surges in the annuals exploiting them. While annual forbs and perennials declined under full protection, annual grasses increased, whereas under rotational and continuous grazing the opposite is observed.

3.4. Conclusions

- Physical seed extraction test resulted in higher soil seed bank size of perennial grasses with low species diversity under rotational grazing. These results show a positive shift in plant community compositions under rotational grazing towards perennial grasses, which is a more ecosystem stability element for arid rangeland.
- Perennial grasses are major components with high ecological significance in arid Mediterranean shrub lands. Their lower physical soil seed bank size under continuous grazing is clear evidence of the damaging effects of continuous overstocking on rangeland ecosystem integrity, productivity and health.
- The zero physical soil seed size with a higher germinable soil seed bank size resulting from vegetative propagation showed the resilience of perennial grasses and significant contributions to arid rangeland integrity.
- The presence of physical with zero germinable soil seed bank size for phanerophytes resulting from mechanical dormancy showed the high complementarity of the two seed bank analysis methods and the necessity of combining them in shrub planting based rangeland rehabilitation program monitoring.
- Germinable soil seed bank testing resulted in high species richness, high similarity index with vegetation cover. It is easy to run at any season and time of the year and highly sensitive to shifts in plant community composition. This makes it a good arid rangeland rehabilitation planning and monitoring tool.

4. Linking vegetation cover and soil seed bank dynamics

Rangelands are self-regenerating natural ecosystems. Incompatible with plowing based sowing and pasture management practices, the soil seed bank is a major rangeland ecosystem component. It is defined as the stock of mature, viable seeds present at soil surface or buried in the soil and litter at a determinate time and place (Qiuyan et al., 2011; Csontos, 2007; Martins & Engel, 2007). Namuta et al. (1964) described the buried seed population in the soil as the mother's womb of plant communities. The soil seed bank is the resting place of seeds and forms an important component of the seed propagated plant life cycles (Gulden & Shirtliffe, 2009). Soil seed bank and vegetation cover are interdependent. Vegetation cover replenishes soil seed bank and depends on it for regeneration.

It is difficult to capture the maximum plant community composition of a natural flora with a single monitoring method. The difficulty arises from the inherent floral heterogeneity of arid Mediterranean rangelands plant communities. In other words, the effects of the inherent spatial and temporal variations in environmental conditions on germination, seedling establishment, vegetative growth, flowering and seed production vary depending on species and plant functional group. Viable seed of some species may remain in soil seed banks for years without germination (Baskin & Baskin, 1988) and some plants from the vegetation cover may also fail to produce seeds. This makes the combination of soil seed bank and vegetation cover based methods used in the present study a more efficient and effective flora monitoring approach.

These traditional monitoring methodologies are still crucial for rangeland management. They complement the newly available geographical information, satellite imaging and remote sensing systems such as Normalized Difference Vegetation Index (NDVI) (Puigdefábregas & Fernández, 2011). In a project aimed at developing maps of land use and vegetation cover in the semi-arid and arid areas of Aleppo and Hama provinces (Syria), (Jaubert et al., 1999), stated that it was proved impossible to differentiate crop species and distinguish between crops and other natural vegetation components without complementary site visits for ground truthing. The new technologies are also indispensable for rangeland monitoring and rehabilitation planning at macro level. The present study made use of the land use maps prepared by the above studies in site selection and benefited from its findings in formulating its hypothesis.

5. Phyto-geographical analysis of the plant communities studied

Using the two vegetation cover and two soil seed bank study methods a total of 137 species from 36 families distributed over 11 chorotypes were recorded in the present study. The 137 species consisted of 102 annuals and 36 perennials. Similar results have been reported in the Fourth National Report on Biodiversity in the Syrian Arab Republic (Anon., 2009). In this report, the Mediterranean and Irano-Turanian chorotypes represent 80% of the Syrian flora, which matches the results found from the present study (Table 1).

Most of the 137 specimens recorded and listed in Table 4 have been identified to species level and a few to genus level; a short description and high resolution illustrative colored images for the plant, flower and seed are provided in the Annex 1 of the thesis.

The 13 most common plant families with the highest species frequencies in the Syrian flora listed in the above-mentioned report were Fabaceae, Compositae, Gramineae, Cruciferae, Labiatae, Umbelliferae, Liliaceae, Scrophulariaceae, Boraginaceae, Ranunculaceae, Chenopodiaceae, Rubiaceae, Euphorbiaceae. All of them were among the highest in the present study (Table 2). The results also showed that levels of Sørensen and Morisita-Horn similarity indices between vegetation cover and soil seed bank are affected by data collection methods.

Table 1: Phyto-geographical analysis of rangeland plant communities studied in northern Syria

Chorotype		Families	Perennial	Annual	Total
Uni-regional	Irano – Turanian	14	11	16	27
	Saharo – Arabian	16	3	17	20
	Mediterranean	11	4	21	25
	American (artificially introduced)	1	2	0	2
Bi-regional	Med – Irano – Turanian	19	5	22	27
	Med – Euro – Siberian	1	1	0	1
	Med – Saharo – Arabian	4	2	2	4
	Irano – Turanian – Saharo - Arabian	8	6	7	13
Pluri-regional	Euro - Siberian - Med – Irano - Turanian	10	1	12	13
	Med – Irano - Turanian – Saharo - Arabian	2	0	3	3
	Plurireginalbor-trop	2	0	2	2
Grand totals		36	35	102	137

Table 2: Most frequent families represented by more than one species in the study area

Family	Species	Perennial	Annual
Compositae	15	1	14
Cruciferae	12	0	12
Gramineae	12	2	10
Chenopodiaceae	11	9	2
Papilionaceae	10	2	8
Caryophyllaceae	8	1	7
Liliaceae	6	4	2
Asteraceae	5	4	1
Scrophulariaceae	5	1	4
Apiaceae	4	0	4
Boraginaceae	4	1	3
Lamiaceae	4	2	2
Euphorbiaceae	3	1	2
Fabaceae	3	1	2
Papaveraceae	3	0	3
Ranunculaceae	3	0	3
Sistaceae	3	0	3
Geraniaceae	2	0	2
Labiatae	2	1	1
Malvaceae	2	0	2
Plantaginaceae	2	0	2
Primulaceae	2	0	2
Rubiaceae	2	0	2
Zygophyllaceae	2	2	0
Grand total	125	32	93

6. Bayesian approach for diversity estimation highlights

6.1. Research question

Shannon and Simpson indices of diversity were, for a long time, the first choice for species diversity assessment. They are measures based on the frequentist approach. Several factors, which underlie the rangeland environment, affect the emergence, reproduction and identification of the emerged plant species and the diversity of the species in a given area. It would probably be more realistic to consider the prevalence or abundances of the species as a random variable than assuming a fixed constant. The Bayesian approach is based on distribution of parameters as prior information and assumes abundance and diversity as random whereas the frequentist approaches do not. A sub-set of the species abundance and diversity data collected for vegetation cover study was used to explore the relative power of the two approaches for estimating diversity indices.

6.2. Methodology

Plant species richness and abundance data from two sites with contrasting grazing management practices, i.e. resting and continuous grazing, were subjected to Bayesian and frequentist approaches of species diversity estimation and the performance was compared through their statistical precision parameters.

6.3. Main findings

The Bayesian diversity estimates were higher than their frequentist counterpart and had lower standard errors. The grazing methods of each site and sites under each grazing method differed significantly in the diversity of plant species. The Bayesian approach resulted in lower p-values compared to the frequentist approach in two out of eight cases reflecting the Bayesian method's higher power. Thus the use of Bayesian approach should be exploited in estimating diversity.

7. Cost-effective storage for *Salsola vermiculata* highlights

7.1. Research question

The shrubby Russian thistle (*Salsola vermiculata* L.) is a major component in the arid Mediterranean rangeland flora and rehabilitation programs of many countries. It is an endemic plant species with high ecology and forage values distributed throughout the arid, semi-arid, saline and hyper saline ecosystems of temperate and subtropical regions (Guma et al., 2010; Wen et al., 2010). It has high self-sowing, direct seeding and transplanting rates of success. It is easily propagated from seed and produces high quality biomass for feed and seed yield for direct sowing under a wide range of rangeland conditions in West Asia and North Africa (Osman et al., 2006). For *S. vermiculata*, the problem is that it loses its germination capability within 6-9 months under ambient storage conditions (Zaman et al., 2010; Osman & Ghassali, 1997).

7.2. Methodology

A completely randomized factorial design with four treatment factors and two replicates was used. The treatment factors were winged or de-winged seeds; high seed moisture content (MC) with vacuum packaging, high MC without vacuum packaging (control), and low MC with vacuum packaging; storage at -21 °C, 4 °C or 24 °C, and storage up to 1140 days (Experiment 1; 2002/2004) or 720 days (Experiment 2; 2003/2005).

Results of germination test at a monthly interval from each treatment combination were subjected to probit analysis to generate seed longevity curves and estimation of periods for 50% drop in seed germination as a measure of seed longevity.

7.3. Main findings

The study reconfirmed previous findings that *Salsola vermiculata* L. is not a recalcitrant species, but an orthodox type with short seed longevity resulting from an above average desiccation susceptibility level. Drying and vacuum packaging alone resulted in a 3.8 to 8.1 fold increase in seed longevity (Fig. 2). This finding is a significant step towards more cost-effective and environmentally friendly rangeland rehabilitation.

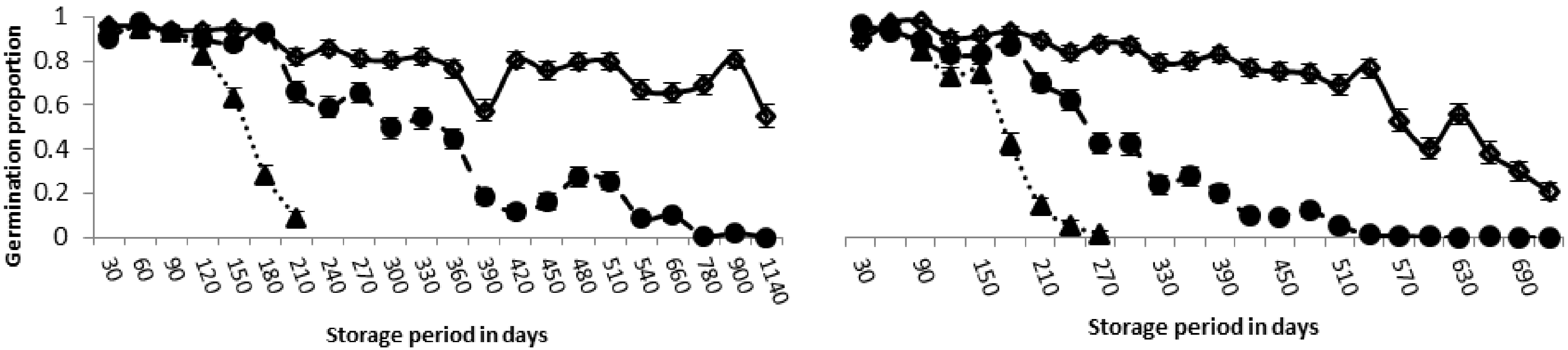

Figure 2: Proportion of germination of de-winged seeds with standard error bars of Salsola vermiculata L. with a moisture content (MC) of 7% and vacuum packaging (VP) (solid line with diamonds), with MC=10.7% and VP (dashed line with circles), and with MC=10.7% and no VP (dotted line with triangles) stored at 24°C for 1140 and 720 days in 2002/04 (left panels) and 2003/05 (right panels), respectively. The low and high MC% for the 2003/05 were 6.5 and 9.6 respectively.

8. Gaps in knowledge

The present study (1) provided quantitative data based information on the impacts of grazing on vegetation cover and soil seed bank under arid Mediterranean rangelands, (2) shed some light on the comparative advantage of Bayesian approaches in plant species diversity estimation, and (3) generated information on the issues of seed quality and longevity in one of the most adapted and widely used goosefoot family shrubs in rangeland rehabilitation.

The discipline of range ecology became into being at the beginning of the 20th century. Scientific research on range ecology was focused on vegetation-herbivore interactions with close linkages to natural resources managements and environmental sciences. It started from simple grazing management trials aimed at acquiring a better understanding of the impact of grazing on vegetation cover (Holechek, 1981). Areas such as range plant ecology to gain better insight into the physical and physiological factors controlling range vegetation cover and soil seed bank dynamics followed (Tessema et al., 2012; Pickett et al., 2008; Samson, 1920). The issues of soil and water conservation become major issues in or criteria for monitoring and evaluation of rangeland conditions (SRM, 1995). With the escalating rangeland degradation, threats of desertification and widespread poverty among rangeland communities, the policy and socio-economic issues have been touched upon (Rae et al., 2001; Alados et al., 2011). The recent boom in space technology provided unique opportunities for large and locale level rangeland monitoring and evaluation through satellite imaging, GIS and remote sensing facilities (Zhao et al., 2011; Hein et al., 2011). Nevertheless, the advances in communication and transportation technologies facilitated access to information on availability of green pastures in remote areas and mass transportation of flocks by trucks, contributing to overstocking.

Based on the above, it can be concluded that rangeland ecology is a century old discipline of science. It benefited from all recent advancements in natural and environmental sciences, research methodologies and technologies. Nonetheless, there are still gaps in the knowledge that need to be filled. Some of these gaps are described below.

a. Lack of site conservation thresholds to guide rehabilitation

Rangelands are natural ecosystems mainly used for animal grazing, amenity and nomadic societal services. The agronomic practices such as opportunistic ploughing, sowing and fertilizer application are known as rangeland encroachments factors. As such, developing empirical site conservation thresholds at which decisions on relaxation of overstocking and excessive exploitation pressure are taken to facilitate recovery is more environmentally sound and cost effective than the current transplanting and reseeding based range rehabilitation programs.

b. Information on ecological significance and management of invasive plants

Poisonous, poorly palatable and thorny plant species are classified as invasive. They increase in population with the decline of palatable species resulting from overstocking. The classification is solely based on short-term economic return ignoring their vital role in soil stabilization and other uses i.e. medicinal. Basic and applied research on the association and facilitation functions of this group of plants would help generate information on the plant density and diversity thresholds at which management actions need to be taken.

c. Range management component of nomadism is poorly understood

It is widely believed that mobility is the main component of nomadism. This may be correct to some extent, but it is difficult to imagine that mobility of nomads is spontaneous, random and purely based on green cover depletion. Taylor et al. (2008) stated that rather than its normal view as the aimless wandering in search of water and pasture, pastoral nomadism is a complex set of practices and knowledge that has permitted the long-term maintenance of a sophisticated "triangle of sustainability" that includes plants, animals, and people. In the Syrian steppes communities 'easterning' and 'westerning' which means migrating towards east and west are common words among the rangeland communities' vocabulary. The cropping areas in Syria are located in the western part of the country adjacent to the Mediterranean coastal line, whereas the steppe is in the east. At the beginning of the summer time in May, nomads move their livestock out of the rangelands towards the cropping areas where crop residues and drinking water are relatively abundant 'easterning'. Towards the beginning of the rainy season at the end of September when perennial plants are at full bloom, they start moving back to the steppe 'westerning'. This cycle of migration significantly contributes to soil conservation through minimizing trampling during the long dry and dust blowing season. To help nomads settle down and facilitate their access to education, municipality and medical services, the Syrian government launched a wide-scale bore well drilling campaign and building of basic infrastructures and facilities in the strategic locations within the steppe. In a meeting to discuss the issues of rangeland degradation and rehabilitation, a rangeland management officer from the Syrian Rangeland Directorate stated with great frustration that the best way to stop and reverse rangeland degradation in the Syrian rangelands was by discontinuing the bore well drilling and closing the existing ones.

Nomadism maybe an old fashioned lifestyle, but is one of the rangeland management options with a proven record of maintaining arid Mediterranean rangelands in good condition for centuries/millennia that we have at the moment to save arid Mediterranean rangelands for future generations. Better understanding of traditional land use and management systems and possibilities and modalities of building on them, seem to me a viable paradigm shift in arid rangeland research for sustainable development. Combining indigenous knowledge with genuine innovations in science and technology could be safer than large-scale application and replication of few decade-long trial results on the fragile arid ecosystems.

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Summary

Rangelands are self-propagating vegetation. They are extensive grazing systems providing feed and living habitat for people, livestock and wildlife. They occupy 40% and 70% of the total land mass of the globe and West Asia and North Africa, respectively. Extending across all the major terrestrial biomes, rangelands are a main source of livelihood for millions and vital ecosystems for environmental health at both macro and local levels.

Rangelands, particularly in the arid and semi-arid areas, are incompatible with intensive pasture management techniques of cultivation, sowing and excessive exploitation. Semi-arid and arid Mediterranean rangelands are fragile ecosystems characterized by hyper-aridity associated with poor nutrient cycling, shallow soils and domination of low germination, slow establishment and growing perennial plants. These characteristics make them highly susceptible to soil erosion resulting from vegetation removal, trampling and wind.

In the rangelands of arid and semi-arid areas of the world, the revolutionary development in the veterinary and animal husbandry sciences and the increasing human populations, led to an exponential increase in the livestock populations to meet the ever rising living standards. These demographical changes, coupled with expanding urbanization and transportation means and infrastructures, inadequate land reform and management policies and practices increased the rates of arid and semi-arid Mediterranean rangelands exploitation far beyond its production capacity.

In an attempt to stop and reverse the degradation, large-scale rangeland rehabilitation programs have been devised and implemented all over the area extending from Morocco in the west to Pakistan in the east and from Turkey in the north to Somali in the south. The plans for the rehabilitation programs were mostly based on establishment of rangeland reserves through halophyte shrub transplanting and grazing management. The grazing management was based on continuous livestock exclusion from the reserves during an initial restoration phase of 3 years followed by an intermittent grazing management system in which grazing is prevented during the critical vegetative growth and fruiting stages in late autumn and in early spring.

The restoration program is based on the assumption that the perennials will protect and help rebuild the top soil layer necessary for its replenishment with a viable, genetically diverse and sizable soil seed bank and aboveground vegetation for environmental health and sustainable feed resources. The program succeeded in establishing vast and impressive shrub stands in many countries. Nevertheless, the cost effectiveness, sustainable management and contribution to reduction of feed shortage are still under debate.

Moreover, little effort has been made to assess the impacts of the program on soil seed bank and above-ground vegetation abundance and diversity replenishment. The studies carried out under this PhD thesis aimed at bridging the above gap in information by generating quantitative data on the impacts of rangeland rehabilitation programs on soil seed bank and above-ground vegetation abundance and diversity replenishment.

The research was carried out under a Mediterranean-type climate of rangelands in northern Syria. Four field-based research projects involving three consecutive seasons of data collection with complementing control environment trials were implemented. The four projects were:

- Impacts of rotational grazing on above-ground plant community composition, abundance and diversity using quadrat and point intercept methods.
- Impacts of rotational grazing on soil seed bank composition, size and diversity using physical seed extraction and germinable soil seed bank testing methods.
- A subset of the germinable soil seed bank data was also used to compare the Bayesian and frequentist based approaches for estimation of species diversity.
- Effects of temperature, relative humidity and moisture content on seed longevity of the highly adapted to arid Mediterranean rangelands, palatable to livestock and used for rehabilitation shrubby Russian thistle (*Salsola vermiculata* L.).

The results from the first research project showed that resting and rotational grazing rehabilitation techniques increased plant density, but not species richness and diversity and that Shannon and Simpson reciprocal indices of diversity were lowest ($P \leq 0.05$) under rotational grazing due to a shift in plant community composition towards the more arid rangeland ecosystem significant perennial grasses.

Simultaneous decline and surge in physical and germinable soil seed bank size of annuals and perennials under the same grazing treatments and sites showed relative differences in root competition and gap exploitation among functional groups. This suggests a plant species facilitation and association relationship between functional groups moderated by the prevalent grazing practices. This could be considered a justification for incorporating herbivore variation and inter-seasonal rotational grazing into the current rangeland rehabilitation program to maintain optimum integrity in plant community composition of arid Mediterranean rangelands.

The continuous grazing treatments with zero level PSSB had 208 seedlings m^{-2} GSSB, which is attributable to seed setting failure resulting from spring overgrazing and vegetative propagation.

Morisita-Horn and Sørensen similarity indices for vegetation measurements with GSSB were higher than with PSSB.

A total of 137 taxa from 121 genera of 36 families distributed over 11 chorotypes were recorded in the two studies. The families Apiaceae, Asteraceae, Boraginaceae, Caryophyllaceae, Chenopodiaceae, Compositeae, Crucifereae, Gramineae, Liliaceae, Papilionaceae, and Scrophulariaceae were the most frequent with a minimum of five taxa under each. The 11 chorotypes with the number of genera covered by each, were Mediterranean - Euro - Siberian and Irano - Turanian with 28 genera from each followed by Mediterranean, Saharo - Arabian, Irano - Turanian – Saharo - Arabian, Euro - Siberian - Med – Irano - Turanian with 24, 20, 14 and 13 genera respectively. The Mediterranean - Saharo-Arabian had four genera and the Irano - Turanian and Mediterranean – Irano - Turanian – Saharo - Arabian and Plurireginalbor-trop with three genera for each. Two artificially introduced species of the Atriplex genera belonging to an American chorotype were also recorded. The plants were identified with a short description and high resolution images of the plants and seeds. The list is a valuable guide for rangeland plants in the Syrian steppes.

The comparison of Bayesian and frequentist diversity indices for estimation of species diversity showed larger estimates with smaller standard errors for the former compared to the later. In addition, significant differences were observed between the diversities of the two sites under each system of grazing management, and also between the two grazing managements at each site. In two out of the six comparisons, the Bayesian approach resulted in lower p-values.

For the study on *Salsola vermiculata* seed longevity, winged seed with high level of dormancy had greater longevity than de-winged seed with higher germinability. De-winged seed with higher moisture content had greater seed longevity. Drying and packaging alone increased longevity by 7.6 and 3.6.

Conclusions

- The simultaneous increase in overall plant density and decrease in species diversity under rotational grazing shows a change in plant community composition moderated by grazing but influenced by site.
- The simultaneous increase in above ground vegetation abundance, physical and germinable soil seed bank size with decrease in species diversity for the perennial grass functional group under rotational grazing suggests that the change in plant community composition shown in the overall plant community resulted from a change in plant species composition towards the low proportional abundance perennial grass species with higher adaptation and competitiveness under arid rangeland ecosystems.

- The simultaneous surge and decline of annuals and perennials under the grazing treatments suggests a grazing moderated plant association and facilitation based change in plant community composition.
- Based on the above, it can be concluded that rotational grazing did not maximize but optimized species diversity and reshaped the plant community in a more arid ecosystem integrity and healthy manner. This probably justifies incorporation of inter seasonal rotational grazing and herbivore variation into the current intra seasonal and sheep dominated grazing system to enhance its impacts and to bring greater sustainability into it.

Physical soil seed bank test is tedious, gives no information on seed quality, with lower similarity indices with vegetation and overestimates potentials for regeneration under arid rangeland conditions

- Germinable soil seed bank underestimates the physical soil seed bank size, but provides more insights into its physiological quality; easier to perform with higher similarity with vegetation, it is a better option for rangeland rehabilitation planning and evaluation.
- In arid Mediterranean rangelands with low frequency of adequate rainfall seasons, GSSB which can be performed at any season and time of the year provides the best possibility to assess the potential and outcome of rehabilitation.
- The larger diversity estimates, more significant differences, lower p-values and smaller standard errors than Shannon and Simpson diversity indices, suggests that the Bayesian approach is a good option for establishing species diversity
- The list of the recorded and illustrated plant taxa and genera generated from the research work is a valuable guide of rangeland plants in the Syrian steppes. A total of 137 species from 11 chorotypes have been recorded.
- The higher seed longevity under higher moisture content found in this study, suggests that desiccation susceptibility is probably the cause of *Salsola vermiculata* L. short seed longevity.
- Increased longevity through drying and packaging alone provide simple, cost-effective and environmentally friendly options to large-scale rangeland rehabilitation programs.
- This study reveals the complexity of ecosystem restoration under arid rangeland conditions and reconfirms the Clements' concept of non-linearity of disturbance with change in community composition.

Samenvatting

In de woeste weidegebieden van Syria komen vegetaties voor die zichzelf in stand houden. Het gaat om dunbevolkte gebieden, waarin vee en wilde dieren grazen. Dit soort woeste weidegronden beslaat 40% van de totale landmassa van de wereld en 70% van de landmassa in het WANA gebied (West-Azië en Noord-Afrika). De woeste weidegronden strekken zich uit over alle belangrijke biomen van de aarde en vormen de belangrijkste bron van inkomsten voor miljoenen mensen. Het zijn tevens ecosystemen die van vitaal belang zijn voor milieu en gezondheid, zowel op macro- als op lokaal niveau.

Woeste weidegronden verdragen een intensieve vorm van beheer of een overmatige exploitatie niet, vooral niet in de aride en semi-aride gebieden. Semi-aride en aride woeste weidegronden zijn kwetsbare ecosystemen gekenmerkt door extreme dorheid, slecht hergebruik van voedingsstoffen, ondiepe bodems en een dominantie van overjarige planten die gekenmerkt worden door slechte kieming, moeizame vestiging en trage groei. Deze eigenschappen maken dat deze woeste weidegronden zeer gevoelig zijn voor erosie als gevolg van verwijdering van de vegetatie, vertrapping en wind.

In de woeste weidegebieden van de aride en semi-aride gebieden van de wereld leidden de revolutionaire ontwikkelingen op veterinair gebied en in de veeteelt-wetenschappen alsmede de sterke groei van de bevolking tot een exponentiële toename van de veestapel. Alleen op deze manier kan aan de alsmaar stijgende levensstandaard worden voldaan. Deze demografische veranderingen, in combinatie met de toegenomen verstedelijking en uitbreiding van transport en infrastructuur, onvoldoende landhervorming en slecht beheer en beleid, leidden tot een intensivering van de exploitatie van de aride en semi-aride gebieden tot een niveau die ver uitsteeg boven het draagvermogen.

In een poging om de degradatie van de woeste weidegronden te stoppen en regeneratie mogelijk te maken, werden grootschalige herstelprogramma's ontworpen en uitgevoerd. Dit vond plaats in het gebied dat zich uitstrekt van Marokko in het westen tot aan Pakistan in het oosten en van Turkije in het noorden tot aan Somalië in het zuiden. De plannen voor herstelprogramma's waren veelal gebaseerd op het instellen van reservaten van woeste weidegronden door middel van het planten van halofyte struiken en een beter beheer van begrazing. Het begrazingsbeheer was gebaseerd op het langdurig buitensluiten van vee uit de reservaten gedurende de eerste drie jaren van herstel, gevolgd door een systeem waarin begrazing slechts met tussenpozen werd toegestaan en in elk geval niet plaatsvond tijdens de kritische fasen van vegetatieve en reproductieve groei in de herfst en in het voorjaar.

Het herstelprogramma is gebaseerd op de veronderstelling dat de meerjarige plantensoorten bescherming zullen bieden en zullen helpen bij het herstellen van de bovenste bodemlaag die nodig is om weer te kunnen komen tot een levensvatbare, genetisch diverse en omvangrijke zaadbank en tot een vegetatie die het milieu en de gezondheid bevordert en duurzame voedselbronnen levert. Het programma is erin geslaagd om in vele landen weer tot een indrukwekkend groot bestand van struiken te

komen. Toch zijn de kosteneffectiviteit, het duurzame beheer en de bijdrage aan vermindering van het tekort aan voeder nog steeds onderwerpen van discussie.

Bovendien is weinig gedaan om de effecten van het programma op de toename van de omvang en diversiteit van de zaadbank en van de vegetatie te evalueren. De studies beschreven in dit proefschrift probeerden in deze leemte te voorzien door kwantitatieve gegevens te genereren over de effecten van herstelprogramma's van de woeste weidegronden op het herstel van de omvang en diversiteit van de zaadbank en van de vegetatie.

Het onderzoek werd uitgevoerd in een mediterraan klimaat op de woeste weidegronden in het noorden van Syrië. Het onderzoeksprogramma omvatte vier typen onderzoek waarin veldwerk gedurende drie opeenvolgende seizoenen werd aangevuld met proeven onder gecontroleerde omstandigheden. De vier typen onderzoek waren:

• De effecten van roterende begrazing op de samenstelling, abundantie en diversiteit van de bovengrondse plantengemeenschap. Hierbij werden verschillende methoden van botanische opnamen toegepast.
• De effecten van roterende begrazing op de samenstelling, omvang en diversiteit van de zaadbank. Ook hier werden twee technieken gebezigd: het zaad werd rechtstreeks uit de bodem gewonnen en geanalyseerd of bodemmonsters werden getoetst op de aanwezigheid van kiemkrachtig zaad door waar te nemen welke planten in de monsters kiemden.
• Een subset van de data betreffende de aanwezigheid van kiemkrachtig zaad werd ook gebruikt om een vergelijking te maken tussen twee benaderingen voor het schatten van de soortenrijkdom in de zaadbank: de Bayesiaanse methode en frequentistische methode.
• Effecten van temperatuur, relatieve luchtvochtigheid en vochtgehalte van het zaad op de levensduur van het zaad van de struikachtige Russische distel (*Salsola vermiculata* L.). Deze soort is zeer geschikt voor de droge mediterrane weidegebieden, wordt door het vee met graagte gegeten en wordt daarom veel gebruikt in herstelprogramma's.

Uit de resultaten van het eerste onderzoeksproject bleek dat rust en afwisselende beweiding de plantdichtheid deden toenemen, maar niet de soortenrijkdom en de soortendiversiteit. De Shannon en Simpson indices van diversiteit waren het laagst ($p \leq 0{,}05$) onder roterende beweiding als gevolg van een verschuiving in de samenstelling van de plantengemeenschap ten faveure van de overblijvende gras-soorten die het vooral goed doen in de ecosystemen van de aride weidegronden.

De gelijktijdige daling en stijging van de omvang van de via fysieke extractie bepaalde (PSSB) en de via kieming bepaalde (GSSB) zaadbank van eenjarige en overjarige planten onder dezelfde begrazingsbehandelingen en op dezelfde locaties toonden aan dat er relatieve verschillen bestaan tussen functionele groepen in de wortelconcurrentie en de exploratie van de ruimte tussen de planten. Dit suggereert een relatie tussen functionele plantengroepen van facilitering en associatie, die door de heersende begrazingsmethoden wordt beïnvloed. Dit kan worden beschouwd als een rechtvaardiging voor het opnemen van variatie in grazers en voor het toepassen van roterende beweiding tussen de seizoenen in het huidige rangeland rehabilitatieprogramma teneinde een optimale integriteit in de samenstelling van de plantengemeenschap van de droge mediterrane woeste weidegronden te behouden.

Daarnaast leverde de continue begrazing geen zaden op via de PSSB methode maar gaf het 208 zaailingen m^{-2} via de GSSB methode, hetgeen te wijten was aan een gebrek aan zaadzetting voortvloeiend uit overbegrazing in het voorjaar en vegetatieve vermeerdering. De “Morisita-Horn similarity indices” en “Sørensen similarity indices” met de vegetatiemetingen waren voor GSSB hoger dan voor PSSB.

In totaal werden in de twee zaadbankstudies 137 taxa van 121 geslachten van 36 families verdeeld over 11 chorotypes gevonden. De families Apiaceae, Asteraceae, Boraginaceae, Caryophyllaceae, Chenopodiaceae, Compositeae, Cruciferaeae, Gramineae, Liliaceae, Papilionaceae, en Scrophulariaceae waren de meest voorkomende, met een minimum van 5 taxa voor elk. De 11 chorotypes met het aantal genera voor elk type waren het Mediterrane - Euro-Siberische en het Irano-Turaanse type met 28 genera voor beide, gevolgd door het Mediterrane, het Saharo-Arabische, het Irano-Turaanse - Saharo-Arabische, en het Euro-Siberische - Med - Irano - Turaanse type met respectievelijk 24, 20, 14 en 13 genera. Het Mediterrane – Saharo - Arabische type had 4 geslachten en het Irano-Turaanse en het Mediterrane - Irano-Turaanse - Saharo-Arabische en Plurireginalbor-trop type hadden 3 geslachten. Er werden tevens twee kunstmatig geïntroduceerde soorten van de Atriplex genera waargenomen die tot een Amerikaans chorotype behoren. De planten werden kort beschreven en er werden hoge-resolutie afbeeldingen gemaakt van de planten en hun zaden. De lijst is een waardevolle gids voor rangelandplanten in de Syrische steppe.

De vergelijking van Bayesiaanse en frequentistische diversiteit indices voor de schatting van de soortenrijkdom vertoonde hogere schattingen met kleinere standaardfouten voor de Bayesiaanse methode in vergelijking met de frequentistische methode. Daarnaast werden significante verschillen waargenomen tussen de diversiteit van de twee locaties in elk systeem van begrazingsbeheer, en ook tussen de twee typen begrazingsbeheer op elke locatie. In twee van de zes vergelijkingen resulteerde de Bayesiaanse aanpak in lagere p-waarden.

In de studie over de levensduur van het zaad van *Salsola vermiculata* bleken de gevleugelde zaden met een diepe kiemrust een langere levensduur te hebben dan de ontvleugelde zaden met een hogere kiemlust. Ontvleugelde zaden met een hoger vochtgehalte hadden een langere levensduur. Drogen en verpakken alleen deden de levensverwachting toenemen respectievelijk met een factor 7,6 en 3,6.

Gebaseerd op de bovenstaande resultaten kan het volgende worden geconcludeerd:

• De gelijktijdige toename van de totale plantdichtheid en de afname van de soortenrijkdom onder roterende beweiding toont een verandering in de samenstelling van de plantengemeenschap aan die zowel door begrazing als door locatie wordt beïnvloed.

• De toename van de bovengrondse vegetatie, de PSSB en de GSSB gekoppeld aan de afname van de soortenrijkdom van de functionele groep overjarige grassen onder roterende beweiding suggereert dat de veranderingen in de plantengemeenschap een gevolg zijn van een verschuiving in de richting van de overjarige grassen die beter aangepast zijn en een groter concurrentievermogen hebben in de ecosystemen van de aride weiden.

• De gelijktijdige toename en afname van eenjarige en overjarige planten onder de beweidingsbehandelingen suggereert een effect van beweiding op de samenstelling van de plantengemeenschap op basis van effecten op onderlinge associatie en facilitering van planten.

• Op basis van het bovenstaande kan worden geconcludeerd dat roterende beweiding de soortenrijkdom niet maximaliseerde maar optimaliseerde. Roterende beweiding deed de plantengemeenschap veranderen in de richting van een gezond en stabiel aride ecosysteem. Dit rechtvaardigt waarschijnlijk het invoeren van een rotatieschema van beweiden over de seizoenen gekoppeld aan variatie in grazers in het beheersysteem dat thans wordt gekenmerkt door beweiding met schapen met rotatie binnen het seizoen. Hopelijk kan daarmee het resultaat van omweiden worden verbeterd en de duurzaamheid van het systeem worden vergroot.

• De fysieke zaadbanktest geeft geen informatie over zaadkwaliteit, is tijdrovend, en geeft niet goed weer wat er in de vegetatie gebeurt. De test overschat de mogelijkheden voor regeneratie van de woeste weidegronden onder droge omstandigheden.

• De test gebaseerd op kiemkrachtige zaden in de zaadbank onderschat de omvang van de fysieke zaadbank, maar biedt meer inzicht in de fysiologische kwaliteit, is makkelijker uit te voeren en geeft resultaten die beter de veranderingen in de vegetatie weerspiegelen. Een dergelijke test is daarom een betere optie voor planning en evaluatie van herstelprogramma’s voor woeste weidegronden.

• In aride Mediterrane woeste weidegebieden waar seizoenen met voldoende regenval een lage frequentie hebben, kan de GSSB test in elk seizoen en op elk tijdstip in het jaar worden uitgevoerd. Deze test biedt de beste mogelijkheden om de potentie en het resultaat van herstel te beoordelen.

• Gezien de hogere schattingen van diversiteit, het grotere aantal significante verschillen, de lagere p-waarden en de kleinere standaardfouten dan bij de Shannon en Simpson diversiteit indices, lijkt de Bayesiaanse benadering een goede optie voor het vaststellen van soortenrijkdom.

• De lijst van waargenomen en geïllustreerde planttaxa en geslachten die op basis van het onderzoek is gegenereerd, is een waardevolle gids van rangeland planten in de Syrische steppe. In totaal werden 137 species van 11 chorotypen waargenomen.

• De langere levensduur van het zaad bij een hoger vochtgehalte, waargenomen in deze studie, suggereert dat gevoeligheid voor uitdroging waarschijnlijk de oorzaak is van de korte levensduur van zaad van *Salsola vermiculata* L.

• Een langere levensduur door middel van drogen en verpakken alleen bieden eenvoudige, kosteneffectieve en milieuvriendelijke opties voor grootschalige rangeland rehabilitatieprogramma's.

• Deze studie laat zien hoe complex het ecosysteem en hoe moeilijk het herstel is van woeste weidegronden onder aride omstandigheden. De resultaten bevestigen het concept van Clements: er is geen lineair verband tussen verstoring en verandering in botanische samenstelling.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (6 ECTS)

- Literature review on impacts of grazing on soil seed bank and aboveground vegetation cover in the Syrian arid Mediterranean rangelands (2011)

Writing of project proposal (4.5 ECTS)

- Impacts of sheep grazing on soil seed bank and aboveground vegetation cover in the Syrian arid Mediterranean rangelands (2006)

Post-graduate courses (3 ECTS)

- Course on ArcGIS for digitisation of spatial and other relevant data, with practical assignments; ICARDA GIS Unit (2008)
- Basic and advanced statistical analysis methods for biodiversity measurements; ICARDA Biocomputing Unit (2010/2011)
- Mixed linear models; PE&RC (2012)

Laboratory training and working visits (4 ECTS)

- Design of national seed system within national agricultural development programme; Eritrea (2010)
- Community based rangeland rehabilitation; Global Environment Facilities (GEF) (2011)

Deficiency, refresh, brush-up courses (3 ECTS)

- Developed, submitted, managed and reported on a USD 15k small grant project proposal on rangeland rehabilitation through direct seeding funded by FAO (2004/07)
- Developed, submitted, managed and reported on a USD 50k cash of small grant on community-based rangeland management and biodiversity conservation funded by the Global Environment Facility managed by UNDP office in Syria (2007/10)
- Currently a member of 3 research project development and implementation committees i.e. Libya agriculture research project (2012/17), Australian funded pasture and forage project in Pakistan and Afghanistan (2012/15) and EU funded food security project for Central and West Asia and North Africa (2012/15)

Competence strengthening / skills courses (1.2 ECTS)

- A 3 days course on adult teaching; ICARDA (2003)
- Scientific publishing workshop; PE&RC (2012)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.2 ECTS)

- PE&RC Weekend (2012)
- PE&RC Day (2012)

Discussion groups / local seminars / other scientific meetings (9.5 ECTS)

- Investigating effects of seed quality on rangeland rehabilitation through direct seeding; work done and presented to the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA) under FAO, Cairo (2009)
- Participation in the ICARDA weekly seminar series as a speaker on measuring biological diversity in and rangelands (2010/2011)
- Participation in the ICARDA multidisciplinary meetings for agricultural research project development, inception, follow-up and reporting (2012)

International symposia, workshops and conferences (12 ECTS)

- Oral presentation to the 30th ISTA Congress, Turkey (2013)on seed longevity of *Salsola vermiculata* L.
- Participation in the Arab Plant Protection Congress; oral presentation; Damascus (2009)
- Participation in the Arab Plant Protection Congress; co-author and oral presentation; Beirut (2011)
- Participation in the Afghanistan annual seed system development meeting under a seed industry development project managed by FAO as facilitator and lecturer (2011)
- Poster presentation on "Bayesian estimation of plant species diversity in arid Mediterranean rangelands under two managements systems in Northern Syria"; Joint Statistical Meeting; San Diego, USA (2012)

Lecturing / supervision of practical's / tutorials (3 ECTS)

- Candidate works at ICARDA as seed production manager and training officer. In this capacity he organizes an average of 5 training courses per year. In these courses he acts as course coordinator and main subject matter specialists (2007-2012)

Supervision of an MSc student (3 ECTS)

- Effects of seed treatment on foliar infestation of *Ascochyta rabei* on chickpea

Curriculum vitae

Personal data	Name	Abdoul Aziz Niane
	Nationality	Senegalese
	Date of birth	05 December 1959
	Marital status	Married with 3 sons
Educational record	BSc in plant protection	Aleppo University, Syria, 1986
	MSc in plant protection	Cukuruva University, Turkey , 1992
Professional record	Seed science & technology research for development assistant at ICARDA	1987-1997
	Seed science & technology research for development associate at ICARDA	1997-2010
	Seed science & technology research for development scientist at ICARDA	2010 to date
Professional expertise and interests	Applied research in seed science and technology particularly in soil seed bank dynamics in arid Mediterranean rangelands	
	Training, capacity building and technical backstopping on national seed system development and diversification	
Awards	ICARDA scientist of the year	2007
	Member of best project implementation team	2008

Annexes

Annex 1. Pair-wise comparison code for Simpson and Shannon-Wiener diversity indices of plant functional groups under the different grazing treatments

CALCULATING SE OF SIMPSON INDICES OF PLANT FUNCTIONAL GROUPS TO COMPARE EFFECTS OF GRAZING ON THEM

```
"------------------ Program 1 ----------------------- "
Open 'SimpsonRecipIndices.txt'; ch=3; fi=out; width=500
Open 'SimpsonRecipCompare.txt'; ch=4; fi=out; width=500
Species ; SpeciesClass
Point[valu=SpeciesClass]Classification
Prin[Ch=3; ipri=*] ':::::::::::: Simpson s species diversity index'
Prin[Ch=4; ipri=*]  ':::::::::::: Simpson s species diversity index'
"----------------------------------------------------"
Scal NSpecClassAll, NSpecClass, N
Calc NSpecClassAll =Nlevel(SpeciesClass)
Prin[Ch=3] ' -------------- Individual sites -------------'
Prin[Ch=4] ' -------------- Individual sites -------------'
Prin[Ch=3] 'Method', 'Site', 'managnt','NSpecClassAll','NSpecClass','Abund',
        'OneByDIndex', 'SeOneByDInd' ; field=12
Print[Ch=4] 'Method', 'Site', 'DClosed','SeDClosed', 'DManaged', 'SeDManaged',
        'DOpen', \
'SeDOpen', 'PrClosVsMang','PrClosVsOpen', 'PrManagVsOpen'; field=12
For i= 'GOT','LIT' ,'QDT', 'Seed'
For j= 'Adamia','Hammam',
        'Ithrya','Maragha','Mshairifeh','Obeisan','Wadiazeeb1','Wadiazeeb2','Mahassa'
        ,'Sheik hilal'
Scal PrClosVsMang,PrClosVsOpen, PrManagVsOpen
Scal DClosed, DManaged, DOpen, SeDClosed,SeDManaged,SeDOpen,Theta
For k='Closed','Managed','Open' ; dumD=DClosed,DManaged, DOpen;
        dumSeD=SeDClosed,SeDManaged, SeDOpen

dele[rede=y]pos0
Rest Abundance, Year, SpeciesClass; DCM.in.i.and.Sites.in.j.and.Grazing.in.k ;
        save=pos0
"Prin Abundance, Year, Species, SpeciesClass"
If Nval(pos0).gt.0
```

```
"Prin  Year, Species, Abundance"
dele[rede=y]ttot, Yr0
Tabu[Class=SpeciesClass] Abundance; total=ttot

Scal Npos0, nYears : Calc Npos0=Nvalue(pos0)
Dele[rede=y]Yr0
Vari[Nval=Npos0] Yr0
Calc Yr0 = Year$[pos0]
Group[rede=y]Yr0 : Calc nYears=Nleve(Yr0)
Calc ttot=ttot/nYears
Dele[rede=y]MnAbundance, Pr
Vari[Nvalues=NSpecClassAll] MnAbundance, Pr
Equa ttot; MnAbundance
dele[rede=y]pos
Rest MnAbundance; MnAbundance.gt.0 ; save=pos
Calc N=sum(MnAbundance)
Calc NSpec=Nvalues(pos)
Scal Npos : Calc Npos=nval(pos)
Vari[Nval=Npos] abundV
Calc abundV = MnAbundance$[pos]
Rest MnAbundance
IF nobs(abundV).gt.0
##seOneByD
Calc dumD=_OneByD
Calc dumSeD=_seOneByD
Prin[Ch=3; squash=y; iprin=*] i, j, k, NSpecClassAll,NSpecClass, N, dumD, dumSeD;
        field=12
Endi
Endi


Endf
 " pairwise comparison"
Calc PrClosVsMang= 2* CUNorm( Abs(DClosed - DManaged)/sqrt(SeDClosed**2+
        SeDManaged**2) )
Calc PrClosVsOpen= 2* CUNorm( Abs(DClosed - DOpen)/sqrt(SeDClosed**2+
        SeDOpen**2) )
Calc PrManagVsOpen= 2* CUNorm( Abs(DOpen - DManaged)/sqrt(SeDOpen**2+
        SeDManaged**2) )
```

```
Prin[Ch=4; ipri=*;Squash=y] i,j, DClosed,SeDClosed, DManaged,SeDManaged,
        DOpen,  \
SeDOpen,PrClosVsMang,PrClosVsOpen, PrManagVsOpen ; field=12
Endf : Endf


"-------over all the sites -------"
 Prin[Ch=3] ' -------------- Overall sites -------------'
 Prin[Ch=4] ' -------------- Overall sites -------------'
Prin[Ch=3] 'Method', 'managnt','NSpecClassAll','NSpecClass','Abund',
        'OneByDIndex', 'SeOneByDInd'; field=12
Print[Ch=4] 'Method', 'DClosed','SeDClosed', 'DManaged','SeDManaged', 'DOpen', \
'SeDOpen','PrClosVsMang','PrClosVsOpen', 'PrManagVsOpen'; field=12

For i= 'GOT','LIT','QDT', 'Seed'
Scal PrClosVsMang,PrClosVsOpen, PrManagVsOpen
Scal DClosed, DManaged, DOpen, SeDClosed,SeDManaged,SeDOpen,Theta
For k='Closed','Managed','Open' ; dumD=DClosed,DManaged, DOpen;
        dumSeD=SeDClosed,SeDManaged, SeDOpen
dele[rede=y] pos0
Rest Abundance, Year, SpeciesClass; DCM.in.i.and.Grazing.in.k ; save=pos0
If nval(pos0).gt.0
dele[rede=y]ttot, Yr0

Tabu[Class=SpeciesClass] Abundance; total=ttot
Scal Npos0, nYears : Calc Npos0=Nvalue(pos0)
Dele[rede=y]Yr0
Vari[Nval=Npos0] Yr0
Calc Yr0 = Year$[pos0]
Group[rede=y]Yr0 : Calc nYears=Nleve(Yr0)
Calc ttot=ttot/nYears
Dele[rede=y]MnAbundance, Pr
Vari[Nvalues=NSpecClassAll] MnAbundance, Pr
Equa ttot; MnAbundance
dele[rede=y]pos

Rest MnAbundance; MnAbundance.gt.0 ; save=pos
Calc N=sum(MnAbundance)
```

```
Calc NSpecClass=Nvalues(pos)
Scal Npos : Calc Npos=nval(pos)
Vari[Nval=Npos] abundV
Calc abundV = MnAbundance$[pos]
Rest MnAbundance
IF nobs(abundV).gt.0
##seOneByD
Calc dumD=_OneByD
Calc dumSeD=_seOneByD
Prin[Ch=3;squash=y; ipri=*] i, k, NSpecClassAll,NSpecClass, N, dumD, dumSeD ;
        field=12
Endif
Endif
Endf

 "pairwise comparison"

Calc PrClosVsMang= 2* CUNorm( Abs(DClosed - DManaged)/sqrt(SeDClosed**2+
        SeDManaged**2) )
Calc PrClosVsOpen= 2* CUNorm( Abs(DClosed - DOpen)/sqrt(SeDClosed**2+
        SeDOpen**2) )
Calc PrManagVsOpen= 2* CUNorm( Abs(DOpen - DManaged)/sqrt(SeDOpen**2+
        SeDManaged**2) )
Prin[Ch=4;iprin=*;Squash=y] i, DClosed,SeDClosed, DManaged,SeDManaged, \
   DOpen, SeDOpen,PrClosVsMang,PrClosVsOpen, PrManagVsOpen ; field=12

Endf
Stop

"------------------ Program 1 ends ----------------------- "
```

```
D = 1 - Sigma(p2i) :
NOTE : THE samWholee letter D is also used here is for 1 by D i.e Simpson's
        Reciprocal index D = 1/(Simpsons div index D)

 RECIPROCAL D = 1/D
   Variance = Var(D)/D^4 ===> SE(1/D) = SE(D)/D^2
10  DELETE [REDEFINE=yes]
        SN,Code,Year,DCM,Sites,Grazing,Familly,Planttypes,\
11  Lifespans,Lifeforms,Lifeform2,Plattability,Species,Richness,Abundance

623  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=3;
        LABELS=!t('Y1','Y2','Y3')\
624  ; REFERENCE=1] Year
625  READ Year; FREPRESENTATION=ordinal
726  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=4;
        LABELS=!t('GOT','LIT','QDT',\
727  'Seed'); REFERENCE=1] DCM
728  READ DCM; FREPRESENTATION=ordinal
829  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=8;
        LABELS=!t('Adamia','Hammam',\
830  'Ithrya','Maragha','Mshairifeh','Obeisan','Wadiazeeb1','Wadiazeeb2')\
831  ; REFERENCE=1] Sites
832  READ Sites; FREPRESENTATION=ordinal
933  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=3;
        LABELS=!t('Closed','Managed',\
934  'Open'); REFERENCE=1] Grazing
935  READ Grazing; FREPRESENTATION=ordinal

 772  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=38;
        LABELS=!t('Amaryllidaceae',\
 773  'Apiaceae','Asphodelaceae','Asteraceae','Boraginaceae','Brassicaceae',\
 774  'Capparaceae','Caryophyllaceae','Chenopodiaceae','Compositeae',\
 775  'Convolvolaceae','Crucifereae','Cyperaceae','Dipsaceae','Euphorbiaceae',\
 776  'Fabaceae','Frankiniaceae','Geraniaceae','Gramineae','Labiateae',\
 777  'Lamiaceae','Liliaceae','Malvaceae','Papaveraceae','Papilionaceae',\
 778  'Papveraceae','Plantaginaceae','Poaceae','Primulaceae','Ranunculaceae',\
 779  'Resedaceae','Rubiaceae','Rutaceae','Scrophulariaceae','Sistaceae',\
 780  'Umbellifereae','Valleriianiaceae','Zygophyllaceae'); REFERENCE=1] Familly
```

```
 781  READ Familly; FREPRESENTATION=ordinal
 1147  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=5;LABELS=!t('Annual
         forb','Perennial forb','Perennial grass','Shrub','Annual grass')\
 1149  ; REFERENCE=1] Life_span
 1150  READ Life_span; FREPRESENTATION=ordinal
1182  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=3;
         LABELS=!t('Forb','Grass',  'Shrub'); REFERENCE=1] Planttypes
 1285  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=2;
         LABELS=!t('Annual','Perennial')\
 1263  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=5;
         LABELS=!t('Chamaephyte','Geophyte','Hemicryptophyte','Phanerophyte','Th
         erophyte')\
 1265  ; REFERENCE=1] Lifeforms
 1266  READ Lifeforms; FREPRESENTATION=ordinal
 1494  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=4;
         LABELS=!t('High','Low','Medium','None'); REFERENCE=1] Plattability
 1496  READ Plattability; FREPRESENTATION=ordinal
  FACTOR [MODIFY=yes; NVALUES=4249; LEVELS=4;
         LABELS=!t('High','Low','Medium',\
 3918  'None'); REFERENCE=1] Plattability
"


"-----Given values---"
"Vari[Values=29, 15, 7, 21, 6, 8,19, 21, 2, 1]abundV
"
Text [Nvalues=25]seOneByD
READ seOneByD
' Scal _nspec, _N : Calc _nspec=nobs(abundV): Calc _N =sum(abundV)'
'Vari[Nvalu=_nspec] _pr: Calc _pr=abundV/_N'
'Scal _D, _OneByD, _seD, _seOneByD'
'Calc _D=sum(_pr*_pr)'
'Calc _OneByD = 1/_D'
"'Compute var(Simpson D) "'
'Scal Nm1, Nm2, Nm3, pi, pj, Epi2,Epj2, sumEpi2Sqr, sumEpi4, sumEpi2pj2'
'Calc Nm1=1-1/_N : & Nm2=Nm1*(1-2/_N) : & Nm3=Nm2*(1-3/_N)'
'Calc sumEpi4 =Nm3*sum(_pr**4) + 6*Nm2*sum(_pr**3)/_N + 7*Nm1*_D/_N/_N
         + 1/_N**3'
'  "Sum(_pr)=1"'
```

```
'Calc sumEpi2Sqr =sum(  (_pr**2+_pr*(1-_pr)/_N)**2  )'
'"Pairwise"'
'Calc sumEpi2pj2 =0'
'For _i=1..._nspec'
'Calc pi= _pr$[_i]'
'Calc Epi2=pi**2+pi*(1-pi)/_N'
'For _j=_i..._nspec'
'If _j.gt._i'
'Calc pj= _pr$[_j]'
'Calc Epj2=pj**2+pj*(1-pj)/_N'
'Calc sumEpi2pj2 = sumEpi2pj2 + Nm3*(pi*pj)**2 + Nm2*pi*pj*(pi+pj)/_N +
        Nm1*pi*pj/_N/_N - Epi2*Epj2'
'Endi'
'Endf'
'Endf'
'Calc _seD=sqrt( sumEpi4 - sumEpi2Sqr +2*sumEpi2pj2 ) : Calc
        _seOneByD=_seD/_D**2 '
:
"
##seOneByD
Prin _D, _OneByD, _seD, _seOneByD
STOP
"

"------------------ Program 2 ---------------------- "
"This finds species SIMPSON diversity indices and compares Management, for each
        Classes"
Open 'IndicesOneByDWithinClass.txt'; ch=3; fi=out; width=500
Open 'CompareOneByDWithinClass.txt'; ch=4; fi=out; width=500
"Create a factor at 1 level for all observations"
Fact[levels=1; labels=!t(All); values= 4249(1); nvalues=4249] Whole

Assign  Plattability; SpeciesClass " Step 1 of 3: Whole, Familly, Planttypes,
        Lifespans,Life_span,Lifeform2,Lifeforms,Plattability//NOTE: modify For
        m= .... 2 places"
"
NOTE : THE same letter D is also used here is for 1 by D i.e Simpson's Reciprocal
        index D = 1/(Simpsons div index D)
```

```
"
Point[valu=SpeciesClass]Classification
Prin[Ch=3; ipri=*] ':::::::::::: Within Classification =  ', Classification
Prin[Ch=4; ipri=*] ':::::::::::: Within Classification =  ', Classification
"---------------------------------------------------"
Scal NSpecAll, NSpec, N
Calc NSpecAll =Nlevel(Species)
Prin[Ch=3] ' -------------- Individual sites -------------'
Prin[Ch=4] ' -------------- Individual sites -------------'
Prin[Ch=3] 'Method', 'Site', 'Category',
        'GrazingMeth','NSpecClassAll','NSpecClass','Abund', 'OneByDIndex',
        'SeOneByDInd' ; field=18
Print[Ch=4] 'Method', 'Site', 'Category', 'DClosed','SeDClosed', 'DManaged',
        'SeDManaged', 'DOpen', \
'SeDOpen', 'PrClosVsMang','PrClosVsOpen', 'PrManagVsOpen'; field=18
For i= 'GOT','LIT' ,'QDT', 'Seed'
For j= 'Adamia','Hammam',
        'Ithrya','Maragha','Mshairifeh','Obeisan','Wadiazeeb1','Wadiazeeb2','Mahassa'
        ,'Sheik hilal'
For m= 'High','Low','Medium','None'" Step 2 of 3: Put here the labels of the grouping
        factor for species"
"'Chamaephyte','Cryptophyte','Hemicryptophyte','Phanerophyte'"
Scal PrClosVsMang,PrClosVsOpen, PrManagVsOpen, Theta
Scal DClosed, DManaged, DOpen, SeDClosed,SeDManaged,SeDOpen   "Simpson
        indices and Ses"
For k='Closed','Managed','Open' ; dumD=DClosed, DManaged, DOpen;
        dumSeD=SeDClosed,SeDManaged, SeDOpen
dele[rede=y]pos0
Rest Abundance, Year, Species;
        DCM.in.i.and.Sites.in.j.and.SpeciesClass.in.m.and.Grazing.in.k ; save=pos0
"Prin Abundance, Year, Species, SpeciesClass"
If Nval(pos0).gt.0
"Prin  Year, Species, Abundance"
dele[rede=y]ttot, Yr0
Tabu[Class=Species] Abundance; total=ttot
Scal Npos0, nYears : Calc Npos0=Nvalue(pos0)
Dele[rede=y]Yr0
Vari[Nval=Npos0] Yr0
```

```
Calc Yr0 = Year$[pos0]
Group[rede=y]Yr0 : Calc nYears=Nleve(Yr0)
Calc ttot=ttot/nYears
Dele[rede=y]MnAbundance, Pr
Vari[Nvalues=NSpecAll] MnAbundance, Pr
Equa ttot; MnAbundance
dele[rede=y]pos
Rest MnAbundance; MnAbundance.gt.0 ; save=pos
Calc N=sum(MnAbundance)
Calc NSpec=Nvalues(pos)
Scal Npos : Calc Npos=nval(pos)
Vari[Nval=Npos] abundV
Calc abundV = MnAbundance$[pos]
Rest MnAbundance
IF nobs(abundV).gt.0
##seOneByD
Calc dumD=_OneByD
Calc dumSeD=_seOneByD
Prin[Ch=3; squash=y; iprin=*] i, j,m, k, NSpecAll,NSpec, N, dumD, dumSeD;
        field=18
Endi
Endi
Endf
 " pairwise comparison"

Calc PrClosVsMang= 2* CUNorm( Abs(DClosed - DManaged)/sqrt(SeDClosed**2+
        SeDManaged**2) )
Calc PrClosVsOpen= 2* CUNorm( Abs(DClosed - DOpen)/sqrt(SeDClosed**2+
        SeDOpen**2) )
Calc PrManagVsOpen= 2* CUNorm( Abs(DOpen - DManaged)/sqrt(SeDOpen**2+
        SeDManaged**2) )
Prin[Ch=4; ipri=*;Squash=y] i,j,m, DClosed,SeDClosed, DManaged,SeDManaged,
        DOpen,  \
SeDOpen,PrClosVsMang,PrClosVsOpen, PrManagVsOpen ; field=18
Endf : Endf : Endf

"-------over all the sites -------"
 Prin[Ch=3] ' -------------- Overall sites -------------'
```

```
 Prin[Ch=4] ' -------------- Overall sites -------------'
Prin[Ch=3] 'Method', 'Category','GrazingMeth','NSpecClassAll','NSpecClass','Abund',
            'OneByDIndex', 'SeOneByDInd'; field=18
Print[Ch=4] 'Method', 'Category', 'DClosed','SeDClosed', 'DManaged','SeDManaged',
            'DOpen', \
'SeDOpen','PrClosVsMang','PrClosVsOpen', 'PrManagVsOpen'; field=18
For i= 'GOT','LIT','QDT', 'Seed'
Scal PrClosVsMang,PrClosVsOpen, PrManagVsOpen
Scal DClosed, DManaged, DOpen, SeDClosed,SeDManaged,SeDOpen,Theta
For m= 'High','Low','Medium','None' " Step 3 of 3: Put here again the labels of the
            grouping factor for species"
"'Chamaephyte','Cryptophyte','Hemicryptophyte','Phanerophyte'"
For k='Closed','Managed','Open' ; dumD=DClosed,DManaged, DOpen;
            dumSeD=SeDClosed,SeDManaged, SeDOpen
dele[rede=y] pos0
Rest Abundance, Year, Species; DCM.in.i.and.SpeciesClass.in.m.and.Grazing.in.k ;
            save=pos0
If nval(pos0).gt.0
dele[rede=y]ttot, Yr0
Tabu[Class=Species] Abundance; total=ttot
Scal Npos0, nYears : Calc Npos0=Nvalue(pos0)
Dele[rede=y]Yr0
Vari[Nval=Npos0] Yr0
Calc Yr0 = Year$[pos0]
Group[rede=y]Yr0 : Calc nYears=Nleve(Yr0)
Calc ttot=ttot/nYears
Dele[rede=y]MnAbundance, Pr
Vari[Nvalues=NSpecAll] MnAbundance, Pr
Equa ttot; MnAbundance
dele[rede=y]pos
Rest MnAbundance; MnAbundance.gt.0 ; save=pos
Calc N=sum(MnAbundance)
Calc NSpec=Nvalues(pos)
Scal Npos : Calc Npos=nval(pos)
Vari[Nval=Npos] abundV
Calc abundV = MnAbundance$[pos]
Rest MnAbundance
IF nobs(abundV).gt.0
```

```
##seOneByD
Calc dumD=_OneByD
Calc dumSeD=_seOneByD

Prin[Ch=3;squash=y; ipri=*] i, m, k, NSpecAll,NSpec, N, dumD, dumSeD ; field=18
Endif
Endif
Endf

 " pairwise comparison"
Calc PrClosVsMang= 2* CUNorm( Abs(DClosed - DManaged)/sqrt(SeDClosed**2+
            SeDManaged**2) )
Calc PrClosVsOpen= 2* CUNorm( Abs(DClosed - DOpen)/sqrt(SeDClosed**2+
            SeDOpen**2) )
Calc PrManagVsOpen= 2* CUNorm( Abs(DOpen - DManaged)/sqrt(SeDOpen**2+
            SeDManaged**2) )
Prin[Ch=4;iprin=*;Squash=y] i,m, DClosed,SeDClosed, DManaged,SeDManaged, \
    DOpen, SeDOpen,PrClosVsMang,PrClosVsOpen, PrManagVsOpen ; field=18
Endf : Endf
Clos Ch=3; fi=out
Clos Ch=4; fi=out
Stop
"------------------ Program 2 ends ----------------------- "
```

Annex 2: Nomenclatures and short description of plants recorded in 10 arid Mediterranean rangeland sites in northern Syria using physical and germinable soil bank tests, quadrate and point intercept vegetation cover

	Description	**Plant and seed images**
1	Species: Aizoon hispanicum L. Family: Aizoaceae Florescence: February to May Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sandy soils Palatability: Low	
2	Species: Amaranthus retroflexus L. Family: Amaranthaceae Florescence: May to October Chorotype: Plurireginalbor-trop Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Weed in cultivated areas Palatability: Low	
3	Species: Bupleurum lancifolium Hornem. Family: Apiaceae Florescence: March to June Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
4	Species: Bupleurum semicompositum L. Family: Apiaceae Florescence: February to April Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sandy soils Palatability: None	

SN	Description	Plant and seed images
5	Species: Coriandrum sativum L. Family: Apiaceae Florescence: March to June Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophpyte Reproduction: Seed Habitat: Sandy soils Palatability: None	
6	Species: Anisosciadium isosciadium Bornm. Family: Apiaceae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophpyte Reproduction: Seed Habitat: Shrub-steppes Palatability: None	
7	Species: Torilis leptophylla (L.) Rchb.f. Family: Apiceae Florescence: March to may Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophpyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
8	Species: Achillea fragrantissima (Forssk.) Sch.Bip. Family: Asteraceae Florescence: March to september Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
9	Species: Artemisia herba-alba Family: Asteraceae Florescence: September to December Chorotype: Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Shrub-steppes Palatability: High	

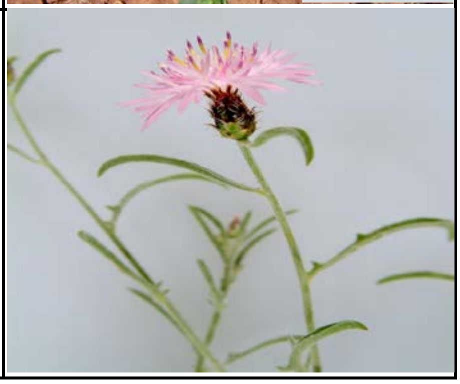
SN	Description	Plant and seed images
10	Species: Matricaria aurea (Loefl.) Sch.Bip. Family: Asteraceae Florescence: February to May Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophpyte Reproduction: Seed Habitat: Nutrient-rich soils, ruderal Palatability: None	
11	Species: Onopordum anisacanthum Boiss. Family: Asteraceae Florescence: June to July Chorotype: Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
12	Species: Picris radicata (Forssk.) Less. Family: Asteraceae Florescence: February to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sand Palatability: Medium	
13	Species: Arnebia tinctoria Forssk. Family: Boraginaceae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sand Palatability: Low	
14	Species: Heliotropium europaeum L. Family: Boraginaceae Florescence: May to October Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Disturbed habitats Palatability: None	

SN	Description	Plant and seed images
15	Species: Moltikia coerula (Willd) Lehm. Family: Borginaceae Florescence: April-June Chorotype: Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Hemichritophyte Reproduction: Seed Habitat: Gypsome soil Palatability: None	
16	Species: Leptaleum filifolium (Willd.) DC. Family: Brassicaceae Florescence: January to March Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes,Salty habitats Palatability: Low	
17	Species: Capparis spinosa L. Family: Capparaceae Florescence: May to September Chorotype: Mediterranean Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Hard rock outcrops,Disturbed habitats Palatability: High	
18	Species: Gypsophila viscosa Murray Family: Caryophyllaceae Florescence: May to June Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sandy Palatability: Low	
19	Species: Herniaria hemistemon J.Gay Family: Caryophyllaceae Florescence: January to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes,Desert,Salty habitats Palatability: None	

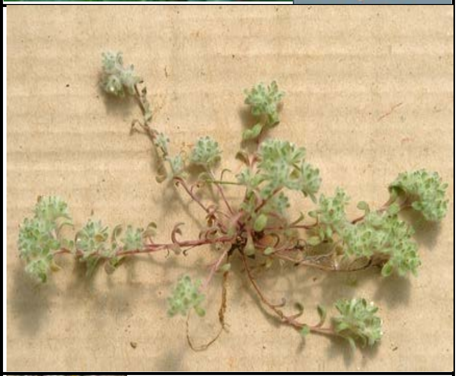
SN	Description	Plant and seed images
20	Species: Holosteum umbellatum L. Family: Caryophyllaceae Florescence: February to April Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
21	Species: Silene coniflora Otth Family: Caryophyllaceae Florescence: March to April Chorotype: Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
22	Species: Spergularia diandra (Guss.) Boiss. Family: Caryophyllaceae Florescence: February to May Chorotype: Med - Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophytee Reproduction: Seed Habitat: Shrub-steppes,Desert,Salty habitats,Nutrient-rich soils, ruderal Palatability: High	
23	Species: Vaccaria pyramidata Medik. Family: Caryophyllaceae Florescence: February to May Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Cultivated areas (weeds) Palatability: Low	
24	Species: Velezia spp. Family: Caryophyllaceae Florescence: March to June Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	

SN	Description	Plant and seed images
25	Species: Dianthus strictus Banks & Sol. Family: Caryophyllaceae Florescence: April to October Chorotype: Mediterranean Plant type: Shrub Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Batha, Phrygana,Shrub-steppes Palatability: None	
26	Species: Anabasis syriaca Iljin Family: Chenopodiaceae Florescence: September to October Chorotype: Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
27	Species: Atriplex canescens (Pursh) Nutt. Family: Chenopodiaceae Florescence: April to October Chorotype: American Plant type: Shrub Life span: Perennial Life form: Phanerophyte Reproduction: Seed Habitat: Wide range Palatability: High	
28	Species: Atriplex halimus L. Family: Chenopodiaceae Florescence: April to October Chorotype: Med - Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Phanerophyte Reproduction: Seed Habitat: Salty habitats Palatability: High	
29	Species: Atriplex leucoclada Boiss. Family: Chenopodiaceae Florescence: April to October Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Desert,Salty habitats,Disturbed habitats Palatability: Low	

SN	Description	Plant and seed images
30	Species: Atriplex polycarpa (Torr.) S. Watson Family: Chenopodiaceae Florescence: April to Octaber Chorotype: American Plant type: Shrub Life span: Perennial Life form: Phanerophyte Reproduction: Seed Habitat: Wide range Palatability: High	
31	Species: Girgensohnia oppositifolia (Pall.) Fenzl. Family: Chenopodiaceae Florescence: May to September Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Solty and desertic habitats Palatability: Low	
32	Species: Haloxylon articulatum Pomel Family: Chenopodiaceae Florescence: October to November Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat:Shrub-steppes Sandy Palatability: Low	
33	Species: Noaea mucronata (Forssk.)Asch. & Schweinf. Family: Chenopodiaceae Florescence: August to October Chorotype: Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
34	Species: Salsola spinosa Lam. Family: Chenopodiaceae Florescence: June to August Chorotype: Irano-Tauranian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Sandy soils Palatability: High	

SN	Description	Plant and seed images
35	Species: Salsola vermiculata L. Family: Chenopodiaceae Florescence: July to September Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Shrub-steppes,Desert,Salty habitats Palatability: High	
36	Species: Salsola volkensii Scweinf. & Asch. Family: Chenopodiaceae Florescence: July to September Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes,Desert,Salty habitats Palatability: Low	
37	Species: Anthemis palestina Boiss. Family: Compositae Florescence: March to June Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
38	Species: Carthamus syriacus Boiss. Family: Compositae Florescence: May to September Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
39	Species: Centaurea ammocyanus Boiss. Family: Compositae Florescence: April to May Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	

SN	Description	Plant and seed images
40	Species: Centaurea aranesa Boiss. Family: Compositae Florescence: April to July Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sand Palatability: Low	
41	Species: Crepis sancta (L.) Bornm. Family: Compositae Florescence: February to April Chorotype: Med - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana , Shrub-steppes , Desert Palatability: None	
42	Species: Filago vulgaris Lam. Family: Compositae Florescence: March to may Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
43	Species: Gymnarrhena micrantha Desf. Family: Compositae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Desert , Sand Palatability: Low	
44	Species: Koelpinia linearis Pall. Family: Compositae Florescence: March to may Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Low	

SN	Description	Plant and seed images
45	Species: Lactuca serriola L. Family: Compositae Florescence: July to October Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Disturbed habitats, Nutrient-rich soils, ruderal Palatability: Low	
46	Species: Lasiopogon muscoides (Desf.) DC. Family: Compositae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Low	
47	Species: Leontodon arabicum Boiss. Family: Compositae Florescence: March to may Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Low	
48	Species: Senecio desfontainei Druce Family: Compositae Florescence: February to April Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: None	
49	Species: Silybum marianum (L.) Gaertn. Family: Compositae Florescence: March to may Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Nutrient-rich soils, ruderal Palatability: Low	

SN	Description	Plant and seed images
50	Species: Sonchus oleraceus L. Family: Compositae Florescence: April Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Cultivated areas (weeds),Disturbed habitats Palatability: Low	
51	Species: Xanthium strumarium L. Family: Compositae Florescence: May to September Chorotype: Plurireginalbor-trop Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Cultivated areas (weeds).Disturbed habitats Palatability: None	
52	Species: Convolvulus betonicifolius Mill. Family: Convolvolaceae Florescence: March to August Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Geophpyte Reproduction: Seed Habitat: Nutrient-rich soils, ruderal Palatability: Medium	
53	Species: Sedum rubens L. Family: Crassulaceae Florescence: March to April Chorotype: Mediterranean Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
54	Species: Diplotaxis harra (Forssk.) Boiss. Family: Cruciferae Florescence: January to May Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophytes Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Low	

SN	Description	Plant and seed images
55	Species: Matthiola aspera Boiss. Family: Cruciferae Florescence: January to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophytes Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Medium	
56	Species: Brasica rapa L. Family: Cruciferae Florescence: March to May Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Cropping areas Palatability: Low	
57	Species: Cardaria draba (L.) Desv. Family: Cruciferae Florescence: March to may Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana , Shrub-steppes Palatability: Low	
58	Species: Erophila verna (L.) Besser Family: Cruciferae Florescence: January to December Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana , Shrub-steppes , Desert, Hard rock outcrops Palatability: Low	
59	Species: Eruca sativa Mill. Family: Cruciferae Florescence: January to April Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	

SN	Description	Plant and seed images
60	Species: Malcolmia crenulata (DC.) Boiss. Family: Cruciferae Florescence: January to December Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
61	Species: Sinapis arvensis L. Family: Cruciferae Florescence: January to December Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
62	Species: Sisymbrium bilobum (K.Koch) Grossh. Family: Cruciferae Florescence: March to April Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
63	Species: Sisymbrium Spp. Family: Cruciferae Florescence: March to April Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
64	Species: Torularia torulosa (Desf.) Hedge & J. Leonard Family: Cruciferae Florescence: January to April Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Medium	

SN	Description	Plant and seed images
65	Species: Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss. Family: Cruciferae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Grass Life span: Annual Life form: Hemicryptohyl Reproduction: Seed Habitat: Sand Palatability: Medium	
66	Species: Carex stenophylla Wahlenb Family: Cyperaceae Florescence: January to April Chorotype: Irano-Turanian Plant type: Grass Life span: Perennial Life form: Geophpyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: Medium	
67	Species: Scabiosa aucheri Boiss. Family: Dipsacaceae Florescence: March to April Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: None	
68	Species: Andrachne telephioides L. Family: Euphorbiaceae Florescence: February to August Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Shrub-steppes, Hard rock outcrops Palatability: None	
69	Species: Chrozophora tinctoria (L.) Raf. Family: Euphorbiaceae Florescence: May to October Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Disturbed habitats Palatability: None	

SN	Description	Plant and seed images
70	Species: Euphorbia spp. Family: Euphorbiaceae Florescence: March to April Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
71	Species: Alhagi graecorum Boiss. Family: Fabaceae Florescence: April to September Chorotype: Med - Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Hemicryptohyl Reproduction: Seed Habitat: Salty habitats , Disturbed habitats Palatability: Medium	
72	Species: Medicago laciniata (L.)Mill. Family: Fabaceae Florescence: February to May Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Distur Palatability: High	
73	Species: OnobrychiS crista-galli (L.) Lam. Family: Fabaceae Florescence: February to May Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Distur Palatability: None	
74	Species: Frankenia hirsuta L. Family: Frankeniaceae Florescence: March to June Chorotype: Med - Euro-Siberian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Salty habitats Palatability: Low	

SN	Description	Plant and seed images
75	Species: Fumaria parviflora Lam. Family: Fumariaceae Florescence: February to May Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
76	Species: Erodium acaule (L.) Becherer & Thell. Family: Geraniacae Florescence: January to September Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Hemicryptohyl Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
77	Species: Erodium glaucophyllum (L.) L'Her. Family: Geraniacae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Hemicryptohyl Reproduction: Seed Habitat: Salty habitats Palatability: High	
78	Species: Eremopyrum bonaepartis (Spreng.) Nevski Family: Graminae Florescence: April to May Chorotype: Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophytes Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
79	Species: Aegilops crassa (Zhuk.) Chennav Family: Graminae Florescence: April to May Chorotype: Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Medium	

SN	Description	Plant and seed images
80	Species: Bromus danthoniae Trin. Family: Graminae Florescence: April to May Chorotype: Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: Low	
81	Species: Bromus tectorum L. Family: Graminae Florescence: March to may Chorotype: Med - Irano-Turanian - Saharo-Arabian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
82	Species: Hordeum glaucum Steud. Family: Graminae Florescence: February to April Chorotype: Med - Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana, Nutrient-rich soils, ruderal Palatability: High	
83	Species: Koeleria phleoides (Vill.) Pers. Family: Graminae Florescence: March to June Chorotype: Med - Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
84	Species: Lolium temulentum L. Family: Graminae Florescence: March to June Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Cultivated areas (weeds) Palatability: Low	

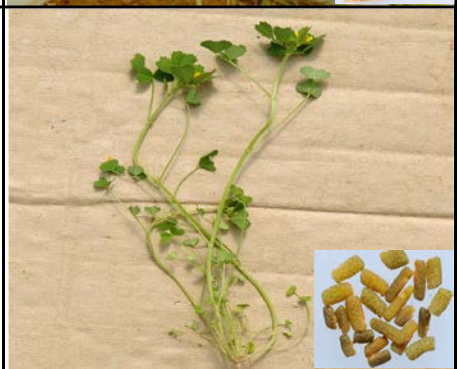
SN	Description	Plant and seed images
85	Species: Schismus arabicus Nees Family: Graminae Florescence: March to April Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes, Distur Palatability: High	
86	Species: Sphenopus divaricatus (Gouan) Rchb. Family: Graminae Florescence: March to may Chorotype: Med - Irano-Turanian - Saharo-Arabian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Desert,Salty habitats Palatability: Low	
87	Species: Stipa barbata auct. non Desf. Family: Graminae Florescence: March to may Chorotype: Irano-Turanian Plant type: Grass Life span: Perennial Life form: Hemicryptohyl Reproduction: Seed Habitat: Hard rock outcrops Palatability: High	
88	Species: Vulpia myuros (L.) C.C.Gmel. Family: Graminae Florescence: February to May Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	
89	Species: Poa bulbosa L. Family: Graminae Florescence: March to April Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Grass Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	

SN	Description	Plant and seed images
90	Species: Teucrium polium L. Family: Labiatae Florescence: Apil to August Chorotype: Med - Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Therophytes Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
91	Species: Lamium amplexicaule L. Family: Labiatae Florescence: January to December Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana, Disturbed habitats,Nutrient-rich soils, ruderal Palatability: None	
92	Species: Teucrium parviflorum Schreb. Family: Lamiaceae Florescence: May-June Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sandy soils Palatability: Low	
93	Species: Marrubium vulgare L. Family: Lamiaceae Florescence: April to June Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Nutrient-rich soils, ruderal Palatability: None	
94	Species: Salvia spinosa L. Family: Lamiaceae Florescence: April to June Chorotype: Irano-Turanian Plant type: Forb Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Shrub-steppes Palatability: None	

SN	Description	Plant and seed images
95	Species: Ziziphora tenuior L. Family: Lamiaceae Florescence: March to may Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: None	
96	Species: Allium aschersonianum Barbey Family: Liliaceae Florescence: February to March Chorotype: Irano-Turanian Plant type: Forb Life span: Perennial Life form: Geophpyte Reproduction: Seed Habitat: Shrub-steppes, Desert Palatability: None	
97	Species: Asphodelus microcarpus Salzm. & Viv. Family: Liliaceae Florescence: January to April Chorotype: Mediterranean Plant type: Forb Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Batha, Phrygana, Shrub-steppes Palatability: None	
98	Species: Bellevalia macrobotrys Boiss. Family: Liliaceae Florescence: March to April Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Geophpyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
99	Species: Gagea fistulosa Ker-Gawler Family: Liliaceae Florescence: March to July Chorotype: Irano-Turanian Plant type: Grass Life span: Annual Life form: Geophpyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	

SN	Description	Plant and seed images
100	Species: Muscari commutatum Guss. Family: Liliaceae Florescence: January to December Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Perennial Life form: Geophpyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
101	Species: Pancratium sickenbergeri aschers. & Schweinf. ex C. & W. Barbey Family: Liliaceae Florescence: September to October Chorotype: Saharo-Arabian Plant type: Forb Life span: Perennial Life form: Geophpyte Reproduction: Seed Habitat: Sand Palatability: None	
102	Species: Malva aegyptia L. Family: Malvaceae Florescence: January to April Chorotype: Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes , Desert Palatability: High	
103	Species: Malva parviflora L. Family: Malvaceae Florescence: February to May Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Nutrient-rich soils, ruderal Palatability: High	
104	Species: Hypecoum procumbens L. Family: Papaveraceae Florescence: March to April Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Low	

SN	Description	Plant and seed images
105	Species: Roemeria hybrida (L.) DC. Family: Papaveraceae Florescence: February to April Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes , Desert Palatability: None	
106	Species: Papaver syriacum Boiss. & Blanche Family: Papaveraceae Florescence: March to May Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
107	Species: Astragalus asterias Hohen Family: Papilionaceae Florescence: March to April Chorotype: Med - Saharo-Arabian Plant type: Forb Life span: Perennial Life form: Geophpyte Reproduction: Seed Habitat: Shrub-steppes , Desert Palatability: None	
108	Species: Astragalus hamosus L. Family: Papilionaceae Florescence: March to May Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
109	Species: Astragalus spinosus (Forssk.) Muschl. Family: Papilionaceae Florescence: February to April Chorotype: Irano-Turanian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Shrub-steppes , Desert Palatability: High	

SN	Description	Plant and seed images
110	Species: Astragalus oocephalus Boiss Family: Papilionaceae Florescence: March to June Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
111	Species: Hippocrepis unisiliquosa L. Family: Papilionaceae Florescence: February to June Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: Medium	
112	Species: Lathyrus inconspicuus L. Family: Papilionaceae Florescence: April to May Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
113	Species: Trigonella aleppica Boiss & Hausskn Family: Papilionaceae Florescence: March to April Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
114	Species: Trigonella radiata Boiss. Family: Papilionaceae Florescence: February to April Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	

SN	Description	Plant and seed images
115	Species: Vicia lutea L. Family: Papilionaceae Florescence: February to June Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
116	Species: Melilotus indicus (L.) All. Family: Papilionaceae Florescence: March to April Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophytes Reproduction: Seed Habitat: Batha, Phrygana Palatability: High	
117	Species: Plantago coronopus L. Family: Plantaginaceae Florescence: March to April Chorotype: Med - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sand Palatability: High	
118	Species: Plantago ovata Forssk. Family: Plantaginaceae Florescence: January to April Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes , Desert Palatability: High	
119	Species: Androsace maxima L. Family: Primulaceae Florescence: March to April Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Tragacanth shrub vegetation (Oro-Mediterranean) Palatability: Low	

SN	Description	Plant and seed images
120	Species: Anagallis arvensis L. Family: Primulaceae Florescence: March to April Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophytes Reproduction: Seed Habitat: Batha, Phrygana Palatability: Medium	
121	Species: Adonis dentata Delile Family: Ranunculaceae Florescence: February to April Chorotype: Irano-Turanian - Saharo-Arabian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppes , Desert Palatability: None	
122	Species: Ceratocephala falcata (L.) Pers. Family: Ranunculaceae Florescence: March to April Chorotype: Med - Irano-Turanian Plant type: Grass Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppe Palatability: None	
123	Species: Nigella arvensis L. Family: Ranunculaceae Florescence: April to July Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sand Palatability: None	
124	Species: Reseda luteola L. Family: Resedaceae Florescence: March to April Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	

SN	Description	Plant and seed images
125	Species: Crucianella ciliata Lam. Family: Rubiaceae Florescence: April Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Shrub-steppe Palatability: None	
126	Species: Galium aparine Family: Rubiaceae Florescence: March to April Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Mediterranean maquis and forest Palatability: None	
127	Species: Haplophyllum longifolium Boiss. Family: Rutaceae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Sand Palatability: None	
128	Species: Linaria chalepensis (L.) Mill. Family: Scrophulariaceae Florescence: January to May Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
129	Species: Linaria joppensis Bornm. Family: Scrophulariaceae Florescence: March to April Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Sand Palatability: Low	

SN	Description	Plant and seed images
130	Species: Parentucellia viscosa (L.) Caruel Family: Scrophulariaceae Florescence: March to June Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
131	Species: Verbascum damascenum Boiss. Family: Scrophulariaceae Florescence: May to August Chorotype: Mediterranean Plant type: Shrub Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
132	Species: Veronica persica Poir. Family: Scrophulariaceae Florescence: February to April Chorotype: Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Disturbed habitats Palatability: Low	
133	Species: Helianthemum aegyptiacum (L.) Mill. Family: Sistaceae Florescence: February to May Chorotype: Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana Palatability: None	
134	Species: Helianthemum ledifolium (L.) Mill. Family: Sistaceae Florescence: February to April Chorotype: Mediterranean Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Batha, Phrygana, Shrub-steppes , Desert Palatability: None	

SN	Description	Plant and seed images
135	Species: Valerianella carinata Loisel. Family: Vallerianiaceae Florescence: April to May Chorotype: Euro-Siberian - Med - Irano-Turanian Plant type: Forb Life span: Annual Life form: Therophyte Reproduction: Seed Habitat: Mediterranean maquis and forest Palatability: None	
136	Species: Fagonia bruguieri DC. Family: Zygophyllaceae Florescence: March to April Chorotype: Saharo-Arabian Plant type: Shrub Life span: Perennial Life form: Chamaephyte Reproduction: Seed Habitat: Desert , Thermophilous plants Palatability: Low	
137	Species: Peganum harmala L. Family: Zygophyllaceae Florescence: March to April Chorotype: Irano-Turanian - Saharo-Arabian (65 species) Plant type: Shrub Life span: Perennial Life form: Hemicryptophyte Reproduction: Seed Habitat: Shrub-steppes Palatability: None	

Funding
This research and thesis preparation are funded by the International Center for Agriculture Research in the Dry Areas (ICARDA) and the Centre for Crop Systems Analysis of Wageningen University, Wageningen, the Netherlands.