# Chapter 5

# Impact of microcatchment water harvesting on the diversity of the Badia rangelands of Jordan

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## 5.1 Introduction

The Badia of Jordan encompasses a wide and significant part of the Hashemite Kingdom of Jordan, covering an area of approximately 72 600 km$^2$, which constitutes 81% of the total area of the country (Allison at al., 1998). The region is subdivided into four major topographic features as follows. (1) The Jordan Rift Valley and Wadi Araba extend from Lake Tiberias in the north to the Gulf of Aqaba in the south. This is the Jordanian part of a continental shelf extending from Aqaba in the south to the Adasiyyah in the north. This zone is divided into three areas: the Jordan Valley, the Southern Ghor, and Wadi Araba. (2) The Highlands extend from the Yarmouk River in the north passing through the Ajloun Mountains, the hills of Ammon and Moab, and the Edom Mountains. Many creeks and wadis drain from the east to the Jordan River, the Dead Sea, and Wadi Araba. (3) The Arid zone (plains) comprises the plains between the Badia (a semi-desert) and the Highlands. (4) The Badia (eastern desert) covers about 8 090 000 ha or 90% of the Kingdom. The Badia is characterized by very sparse vegetation cover and an annual rainfall of < 200 mm. In the past it was only used for grazing. In the last two decades, however, 20 000 ha has been irrigated, using underground water, to grow vegetables (especially tomato, watermelon, and potato), fruit trees and cereals, particularly wheat.

The Mharib pilot site is located about 65 km south-east of Amman in Jordan (31.672358° N and 36.21763° E). It consists of a sub-watershed of 30 ha and 7 ha as the net site area. The Mharib community consists of 30 households with a population of 300 inhabitants. Land use is mainly rangeland and barley cultivation. Some of the population are nomads and travel with their flocks to distant areas in search of better feed. The average flock size is around 200 heads per holder. The grazing period for the community is 2–5 months, according to the rangeland situation. The average annual rainfall is 152 mm, and sporadic with most during short intense storms. Surface runoff is medium (ICARDA, 2007).

The area lies wholly within the xeric–aridic transitional moisture regime. The Mharib region lies within the grassland steppe vegetation zone. Barley is grown in the valley bottom alluvium, where the moisture from the limited rainfall is augmented by runoff from the hill slopes (ICARDA, 2007). The dominant plants are *Anabasis* and *Poa* spp. Some *Achillea*, *Colchicum*, and *Salsola* spp. can also be seen in the area. The steppe grassland produces a tough turf, which protects the soil surface from wind and water erosion. Frequent grazing keeps vegetation growth close to the soil surface (BBM Annual Report, 2005). Rangeland degradation has severely affected the biodiversity of plants and other organisms, and in many cases palatable plant species have been entirely eliminated from plant communities (Al-Jaloudy, 2001). Factors such as the climatic conditions (causing declining rainfall; Blench, 1995), droughts and depletion of soil nutrients, overgrazing, premature grazing, and overuse of natural resources by humans has resulted in the decline of native vegetation in the Badia region (Al-Jaloudy, 2001) and loss of indigenous plants. Other problems are related to the uprooting of bushes for firewood by pastoral communities, uncontrolled arbitrary movement of vehicles in grazing lands, and increasing livestock densities (Al-Jaloudy, 2001). Other environmental problems can be related to plowing of marginal lands to guarantee property rights over the land (Abu-Zanat 1997) and plastic waste in rangelands adjacent to agricultural areas (Blench, 1995).

Sound knowledge of the biodiversity status of the rangeland and its degradation levels will help scientists and planners to develop technical and socioeconomic solutions aimed at restoration of the vegetation and the sustainability of rangeland. In dry areas, water, not land availability, is the most limiting resource for improved agricultural production. Maximizing water productivity, and not yield per unit of land, is therefore a better strategy for dry farming systems (Oweis and Hachum, 2006). Shaping the ground to concentrate available rainfall has been very effective for establishment of vegetation in deserts. Microcatchment systems provide many advantages over alternative irrigation schemes. They are simple and inexpensive to construct and can be built rapidly using local materials and manpower and, once constructed, little maintenance is required (Bainbridge, 2003).

Many plant species are severely affected by rangeland degradation resulted from overgrazing and cultivation of barley. Microcatchment water harvesting (WH) systems associated with suitable grazing management provide an opportunity for plant regeneration and improving vegetation. However, there is no information and/or research work on the potential and constraints associated with regenerating the native vegetation in the Badia regarding the best way and the impact on diversity of plant species and vegetation cover. This study aimed at conducting the followings activities:

- To survey and identify the flora at the Mharib watershed (the intervention area of the Badia Benchmark Project),
- to study the effect of microcatchment WH techniques on the soil seed bank compared with the current situation,
- to evaluate the effect of microcatchment WH on the native vegetation regeneration and improvement, and
- to multiply and reintroduce the annual native plant species collected from the rangelands.

The study is presented in five main sections:

- Documentation of the flora of the Mharib watershed,
- Assessment of the soil seed bank under different microcatchments,
- Evaluation of the effect of microcatchment WH on native vegetation,
- Regenerating native vegetation cover using WH techniques, and
- Evaluation of the potential of seed of native plant species for multiplication/propagation.

## 5.2 Documentation of the flora of the Mharib watershed

### 5.2.1 Materials and methods

The Mharib pilot site exists within a sub-watershed of 30 ha, with 7 ha as the net site area for the intervention. The intervention sites (sites where WH microcatchments were implemented) were established between November 2005 and January 2006 on an area of 27.1 ha divided into 28 sites where different intervention techniques were implemented. The sites were identified by taking GPS points for their boundaries, and converted into maps using the GIS lab facilities at the National Center for Agricultural Research and Extension (NCARE). For each intervention site the following characteristics were recorded: area, site description, shrub species, slope class, slope (%), surface crust class, soil depth class, soil depth (cm), stone cover class, gravel (%), stone (%), boulders (%), rock outcrop class, infiltration rate, soil properties (pH and electrical conductivity), organic matter (%), P (ppm), K (ppm), and percentage of $CaCO_3$ (Annex 1.1).

A native vegetation field survey was conducted for each of the above sites using the Belt transects method (Schmutz et al., 1982). A 50-m-long transect line was laid out across the area to be surveyed and a 1-$m^2$ quadrat was placed on the first marked point on the line and at 10-m intervals on both sides, making a total of five quadrats per line (Figure 5.1). Two transects were taken: one between the contour ridges (catchment area), and the other within the WH contour ridges (planted area). This was done for each 0.6 ha, referred to as a sub-site (even if the site area was < 0.6 ha it was considered as one sub-site), making a total of 114 transects and 570 quadrats for each survey date (Table 5.1).

Vegetation cover percentage, stone cover percentage, and the individual plants inside the quadrat were then determined. Individual plants for each species were counted (Kutiel and Danin, 1987) and recorded. Species identification was performed in the field for known species (Zohary, 1966; Al-Eisawi, 1998).

ICARDA's passport data sheets (Annex 1.2) were filled for the study site. The documentation process was carried out twice during this study (December 2006 and April 2007) to determine whether there was any change in vegetation cover with time.

The following parameters were recorded and computed for each site:
Vegetation (shrubs and grasses) cover – the area of the quadrat occupied by the aboveground parts of a species when viewed from above.

Stone cover percentage – visually estimated and recorded for each quadrat.

Species richness (SR; Wilson and Shmida, 1984) – simply calculated by counting the number of species of a site.

Rank-abundance curves (Preston, 1948) – obtained by plotting abundance rank as the X-axis against species proportional abundance (log10 scale) as the Y-axis.
Shannon–Wiener Diversity Index (SDI) (Whittaker, 1972) – calculated using the formula:

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

**H:** Shannon's diversity index (SDI).
**SR:** total number of species in the community (richness)
**$P_i$:** proportion of S made up of the $i^{th}$ species

Shannon's equitability ($E_H$) – calculated by dividing H by $H_{max}$ (here $H_{max}$ = lnS)

$$EH = H/H_{max} = H/\ln S$$

Annuals–perennials ratio (AP-ratio) – calculated using the formula

$$AP\text{-}ratio = A/(A+P)$$

**A:** number of individual annual plants
**P:** number of individual perennial plants
Plant families – the number of different plant families found in the area.
Forbs/Herbs species – the number of forbs/herbs plants recorded.

**Flora map**

The objective was to identify the variety of vegetation associated with the sub-watersheds and then establish the extent and distribution of the community. ICARDA's passport data sheet (Annex 1.2) was used here and only species recorded in the spring survey were entered onto the map. A legend was created to identify the species easily on the map. As a result, a flora map was obtained with a detailed description of vegetation.

**Table 5.1. Area (ha), number of transects, and number of quadrats, between and within contour ridges, of the intervention sites in the Mharib area.**

| Site name | Area (ha) | Site description | No. of transects | | No. of quadrats | |
|---|---|---|---|---|---|---|
| | | | Between rows | Within rows | Between rows | Within rows |
| MH1CRS | 0.6 | Mharib, Plot 1, Contour Ridges, Shrub | 1 | 1 | 5 | 5 |
| MH3CRSa | 0.94 | Mharib, Plot 3, Contour Ridges, Shrubs, Sub Site a | 2 | 2 | 10 | 10 |
| MH3CRSb | 3.61 | Mharib, Plot 3, Contour Ridges, Shrubs, Sub Site b | 6 | 6 | 30 | 30 |
| MH3CRSc | 1.96 | Mharib, Plot 3, Contour Ridges, Shrubs, Sub Site c | 3 | 3 | 15 | 15 |
| MH4CRSa | 0.49 | Mharib, Plot 4, Contour Ridges, Shrub, Sub Site a | 1 | 1 | 5 | 5 |
| MH4CRSb | 0.41 | Mharib, Plot 4, Contour Ridges, Shrub, Sub Site b | 1 | 1 | 5 | 5 |
| MH6CRSa | 0.23 | Mharib, Plot 6, Contour Ridges, Shrubs, Sub Site a | 1 | 1 | 5 | 5 |
| MH6CRSb | 0.33 | Mharib, Plot 6, Contour Ridges, Shrubs, Sub Site b | 1 | 1 | 5 | 5 |
| MH7CRS | 0.13 | Mharib, Plot 7, Contour Ridges, Shrub | 1 | 1 | 5 | 5 |
| MH8CRS | 0.33 | Mharib, Plot 8, Contour Ridges, Shrub | 1 | 1 | 5 | 5 |
| MH9CRS | 0.18 | Mharib, Plot 9, Contour Ridges, Shrub | 1 | 1 | 5 | 5 |
| MH10CRS | 0.12 | Mharib, Plot 10, Contour Ridges, Shrub | 2 | 2 | 10 | 10 |
| MH12VSa | 0.21 | Mharib, Plot 12, Vallerani, Shrub, Sub Site a | 3 | 3 | 15 | 15 |
| MH12VSb | 0.61 | Mharib, Plot 12,Vallerani, Shrub, Sub Site b | 1 | 1 | 5 | 5 |
| MH13VS | 0.61 | Mharib, Plot 13,Vallerani, Shrub | 1 | 1 | 5 | 5 |
| MH14VS | 1.73 | Mharib, Plot 14,Vallerani, Shrub | 3 | 3 | 15 | 15 |
| MH17VSa | 1.72 | Mharib, Plot 17, Vallerani, Shrub, Sub Site a | 3 | 3 | 15 | 15 |
| MH17VSb | 1.65 | Mharib, Plot 17, Vallerani, Shrub, Sub Site b | 3 | 3 | 15 | 15 |
| MH17VSc | 4.51 | Mharib, Plot 17, Vallerani, Shrub, Sub Site c | 8 | 8 | 40 | 40 |
| MH17VSd | 0.53 | Mharib, Plot 17, Vallerani, Shrub, Sub Site d | 1 | 1 | 5 | 5 |

Table 5.1. (Continued).

| Site name | Area (ha) | Site description | No. of transects | | No. of quadrats | |
|---|---|---|---|---|---|---|
| | | | Between rows | Within rows | Between rows | Within rows |
| MH19VSa | 0.84 | Mharib, Plot 19, Vallerani, Shrub, Sub Site a | 2 | 2 | 10 | 10 |
| MH19VSb | 0.21 | Mharib, Plot 19, Vallerani, Shrub, Sub Site b | 1 | 1 | 5 | 5 |
| MH20CRS | 0.29 | Mharib, Plot 20, Contour Ridges, Shrub | 1 | 1 | 5 | 5 |
| MH21CRSa | 0.49 | Mharib, Plot 21, Contour Ridges, Shrub, Sub Site a | 1 | 1 | 5 | 5 |
| MH21CRSb | 1.17 | Mharib, Plot 21, Contour Ridges, Shrub, Sub Site b | 2 | 2 | 10 | 10 |
| MH22VSa | 1.01 | Mharib, Plot 22, Vallerani, Shrub, Sub Site a | 2 | 2 | 10 | 10 |
| MH22VSb | 10.3 | Mharib, Plot 22, Vallerani, Shrub, Sub Site b | 2 | 2 | 10 | 10 |
| **Total** | **27.01 ha** | | **57** | **57** | **285** | **285** |
| **Grand total** | **27.01 ha** | | **114** | | **570** | |

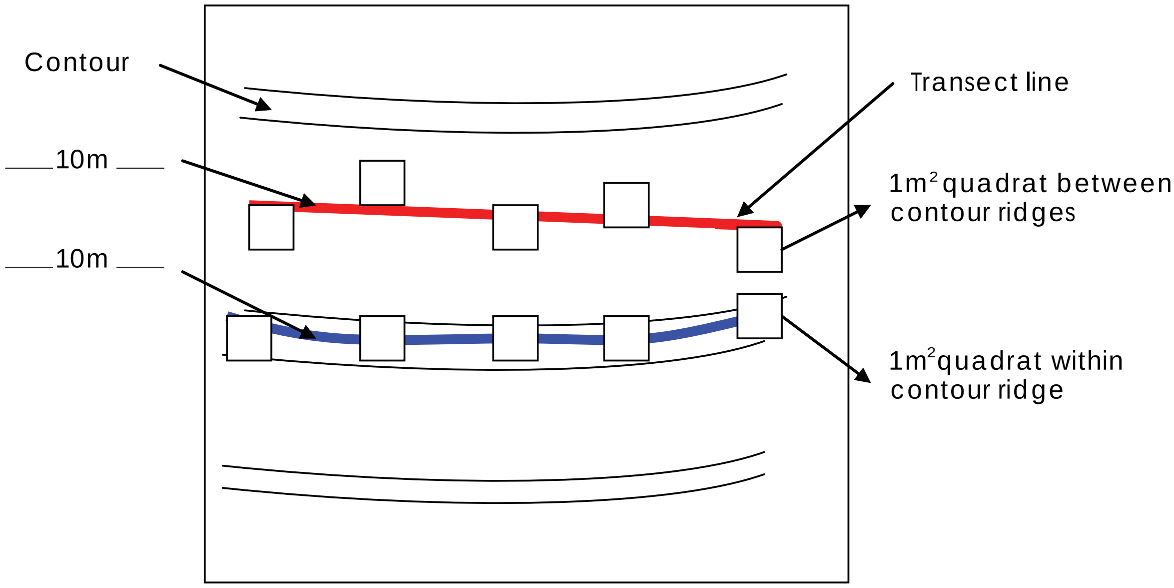


**Figure 5.1. Layout of the sampling technique in the field.**

### 5.2.2 Results and discussion

#### Vegetation cover

Vegetation cover percentages for the microcatchment watersheds were mapped in GIS format to easily distinguish between the vegetation situation in autumn (December 2006) and spring (April 2007) (Annexes 1.3–1.6). These maps clearly showed higher vegetation cover percentages in spring compared to autumn. The average vegetation cover for sites planted in November 2005 was higher (32%) than those planted in January 2006 (28%) in the autumn survey. Similar results were obtained in spring, where the average vegetation cover for sites planted in November 2005 were higher (53%) than those planted in January 2006 (46%). Vegetation cover percentages were almost double in most sites in spring compared to autumn.

The higher vegetation cover in April 2007 over December 2006 was expected since April is spring, when the plants flourish and increase vegetative growth and cover.

In December 2006, the vegetation cover percentages were highest (47%) for site 7CRS, and lowest (20%) for site 19VSb (Table 5.2). The average vegetation cover for all sub-watershed sites was 29.5%; with around 43% of sites with vegetation cover above the overall average. The average vegetation cover of the sub-watershed sites with the traditional plow contour ridges planted with shrubs (CRS) was higher (30.8%) than the sub-watershed sites with the intervention of Vallerani contours planted with shrubs (27.8%). The average vegetation cover of the sub-watershed sites established in November 2005 was higher (30.9%) than those established in January 2006 (27.9%), but lower than site 10CRS that was established in December 2004 (40%).

The increase in the number of the annual species that usually grow after the rainy season may be the main reason for increased vegetation cover. Rainfall is the major climatic factor influencing inter-annual variations of average vegetation cover. Such results are consistent with those of (Ayyad 1973) and (Kutiel et al. 2000), who found that the annual plant growth and number in dry areas were highly dependent on the climatic conditions, mainly rainfall.

In April 2007, the highest vegetation cover (69.7%) was at site 3CRSc and the lowest (28%) at site 18CRS (Table 5.2). The average vegetation cover for all sub-watershed sites was 49.3%, with around 53.6% of sites above the average. The average vegetation cover of CRS sites (50.2%) was higher than sites with the intervention of Vallerani planted with shrubs (17VSa, 17VSb, 17VSd and 13VS) (45.0%). The average vegetation cover of sub-watershed sites established in November 2005 was higher (53.5%) than for site 10CRS established in December 2004 (47.5%) or sites established in January 2006 (46.4%).

The increase in the number of the annual species that usually grow after the rainy season may be the main reason for increased vegetation cover. Rainfall is the major climatic factor influencing inter-annual variations of average vegetation cover. Such results are consistent with those of (Ayyad 1973) and Kutiel et al. (2000), who found that the annual plant growth and number in dry areas were highly dependent on the climatic conditions, mainly rainfall.

The highest vegetation cover in the first sampling was for MH7CRS (47%) with a south-facing slope, and the lowest for MH-19VSb (20%) with an east-facing slope. In south-facing slopes, the soils kept greater moisture content than those of other slopes; while east-facing slopes lost their moisture more rapidly before midday due to the earlier sun rise and the high day temperatures. This may be the main reason why MH7CRS (despite the small area of about 0.13 ha kept the highest vegeta-

**Table 5.2. Vegetation cover percentages for the two survey dates (December 2006 and April 2007) in the sub-watersheds of the Mharib area.**

| Site | Vegetation cover (%) Dec. 2006 | Vegetation cover (%) Apr. 2007 | Site | Vegetation cover (%) Dec. 2006 | Vegetation cover (%) Apr. 2007 |
|---|---|---|---|---|---|
| 7CRS | 47 | 56 | 21CRSb | 28.8 | 50.5 |
| 10CRS | 40 | 47.5 | 14VS | 28.5 | 55 |
| 17VSa | 39.5 | 49. 7 | 17VSc | 28.3 | 48 |
| 8CRS | 39 | 54 | 9CRS | 26 | 50 |
| 17VSb | 37.9 | 58.3 | 4CRSa | 25.5 | 45 |
| 13VS | 35 | 46 | 6CRSa | 23 | 40 |
| 3CRSc | 34 | 69.7 | 12VSa | 23 | 37.3 |
| 17VSd | 33.8 | 44.17 | 22VSb | 22.8 | 49.5 |
| 3CRSa | 33.75 | 57.5 | 19VSa | 22 | 56 |
| 6CRSb | 32.5 | 52 | 12VSb | 21.5 | 43 |
| 21CRSa | 32.5 | 45 | 18CRS | 21.5 | 28 |
| 20CRS | 30.5 | 43 | 22VSa | 21 | 47.9 |
| 4CRSb | 29.5 | 58 | 1CRS | 20.5 | 50 |
| 3CRSb | 29.4 | 56.2 | 19VSb | 20 | 44 |

tion cover after the hot summer season. MH7CRS refers to Mharib, Plot 7, and Contour Ridges, planted with *Atriplex halimus* on November 2005, and was the smallest area of the sub-watersheds. MH19VSb refers to Mharib, Plot 19, Vallerani, Sub Site planted with *Atriplex halimus* on January 2006 – a year after MH7CRS.

**Total number of plants**

The number of individual plants/m$^2$ was counted for the two survey dates. In December 2006 there was a clear difference among the sub-watershed sites, with the highest number of plants of 61 plants/m$^2$ at site 7CRS. This was 577% higher than the lowest number (9 plants/m$^2$) at sites 12VSb and 19VSa (Figure 5.2). For April 2007 (Figure 5.3), the total number of individual plants had increased by about 93%. The highest number of plants was at site 8CRS (815 plants/m$^2$) which was 570 higher than the lowest number of plants at site 22VSb (118 plants/m$^2$).

The dominant plant species found in the December 2006 survey was *Poa bulbosa* L. (257 plant/m$^2$ in site 17VSc), followed by *Torularia torulosa* (Desf.) O.E.Scultz (23 plants/m$^2$ in site 3CRS). However, there was a very low number of *P. bulbosa* plants (9 plants/m$^2$) in site 12VSb. Other plant species were also recorded in the study area in very small numbers compared to *P. bulbosa.* For example, in site 17VSc, the number of other plant species was about 35% that of *P. bulbosa*. Moreover, *P. bulbosa* was found in all sub-watershed sites. *Poa bulbosa* and *T. torulosa* were dominant plants in the area before the intervention, and were the site characteristic species (BBM Annual Report, 2005).

**Rank species abundance**

The autumn survey curves were steeper than those for spring, indicating that the area was more disturbed in terms of the presence of plant species with uneven proportions, i.e. a few (one or two) plants

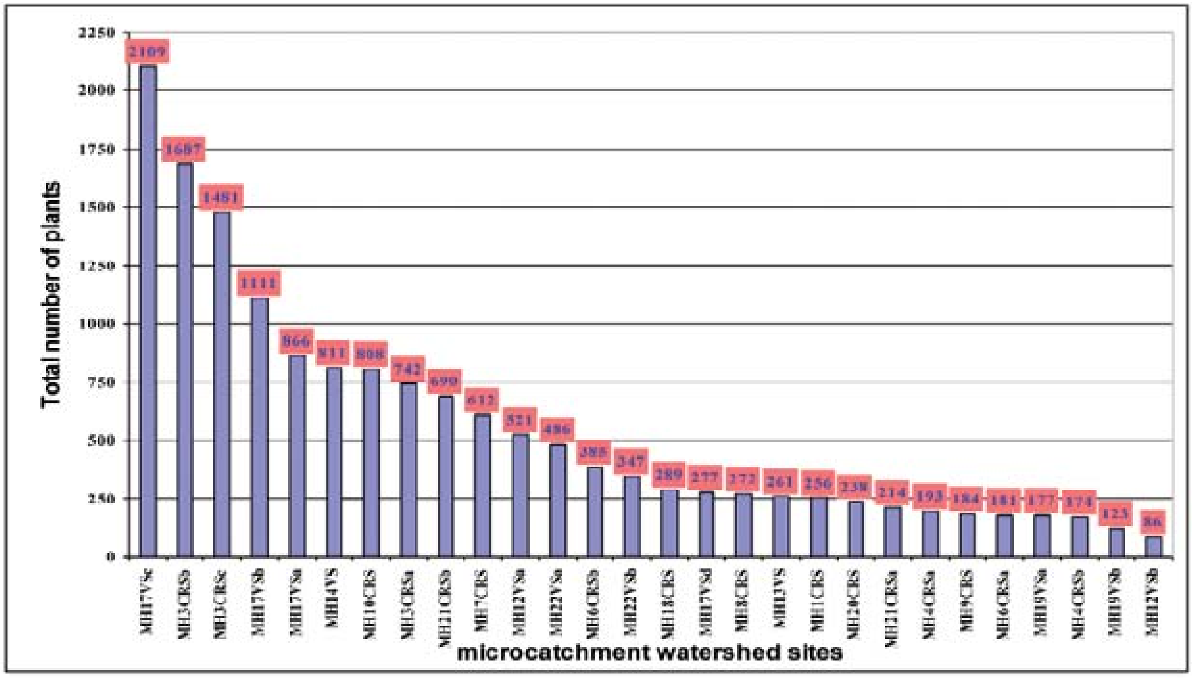


**Figure 5.2. Total number of plants/m² in the Mharib intervention area during December 2006 survey.**

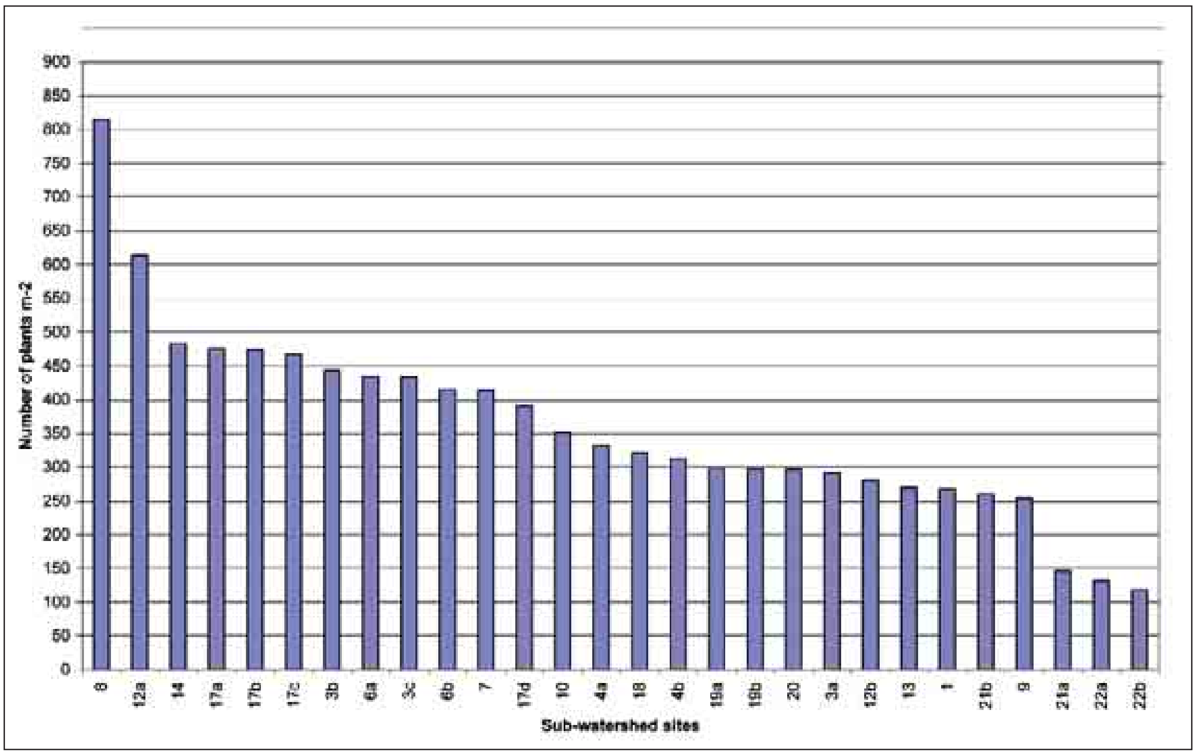


**Figure 5.3. Total number of plants/m² in the Mharib intervention area during April 2007 survey.**

had the most individuals in the community. This may be a result of shrubs being the main dominant species in the area in autumn. Since our sites are located in dryland, which has been subjected to a long history of disturbance (overgrazing and soil erosion), the dominant shrubs are mainly one or two species with low palatability.

MH4CRSb contained eight species and 88% of the plants were *P. bulbosa*. MH6CRSa contained six species with 60% being *T. torulosa* and 27% *Gymnarrhena micrantha Desf.* MH8CRS contained six species, being 61% *P. bulbosa* and 22% *G. micrantha*. MH17VSa contained seven species with 58% *P. bulbosa*, 19% *T. torulosa*, and 12% Anabasis syriaca Iljin. MH18CRS also contained seven species with 76% *P. bulbosa* and 11% *G. micrantha*. MH21CRSb contained 11 plant species with 50% being *P. bulbosa* and 41% *G. micrantha.*

These above sites (communities) were characterized by different slopes, which indicated the different proportions of species in these sites. Such results show the highly uneven proportionate distribution of plants among the different species in their community.

Native species in sites MH17VSb, MH17VSc, and MH8CRS in the spring survey were more evenly distributed than in automn. MH17VSb contained 27 plant species: 30% *T. torulosa*, 14% Phalaris minor Retz, 13% *Hammada eigü Iljin*, 7% *P. bulbosa* and 5% *Bassia muricata* (L.) Ascherson. MH17VSc contained 30 species: 42% *T. torulosa*, 15% Ph. minor, 14% Ha. eigü, and 8% B. muricata. MH8CRS contained 23 plant species: 30% *T. torulosa*; 10% *Schismus barbatus L.*; 8% *P. bulbosa*; 7% each of *Silene conoides L.* and *Lasiopogon muscoides L.*; and 5% each of *Ha. eigü, Holostium glutinosum,* and *Hordeum glaucum Steudel.* The total plants were represented by 2–5 plant species within the community, giving an even proportional distribution of different species.

The results showed that in the spring survey, the Species Richness (SR) increased and almost doubled compared to the autumn survey; this is reflected by the evenness of distribution of the species in the areas. Sites MH18CRS, MH19VSa, MH21CRSa, and MH21CRSb contained, even in spring, species that were unevenly distributed.

**Species Richness (SR)**

During the autumn survey, SR for all microcatchment watersheds ranged from 2% (five species) for MH6CRa, MH10CRS, and MH12VSb to 6% (14 species) in MH17VSc (Figure 5.4). For the spring survey, the SR was higher and ranged between 1% (seven species) for MH18CRS and 5% (35 species) for MH12VSa (Figure 5.5). There was an overall increase in SR in all sites from December 2006 to April 2007. The mean increase in SR was almost 13% over all sites, with an increase ranging from SR = 6 in MH21CRSb to SR = 33 in MH12VSa and MH17VSa. This was due entirely to the significant rainfall during the 2006/07 winter. This obtained values are similar to those of Badman (2006). The increase in SR in spring compared to autumn was a result of new species that emerged or appeared in spring.

Mainly annual plants appeared during spring as a result of the rain, consistent with the findings of (Aronson and Shmida 1992) and (Russi et al. 1992). Annual species represented 5–90% of the native vegetation recorded in the different watershed sites. Environmental factors, including both biotic and biotic stresses, largely determined the relative SR as well as the composition of the 'community' or 'taxons' at a given site.

**Shannon–Wiener Diversity Index (SDI) and Shannon's Equitability (EH)**

In the autumn survey, the highest SDI was at MH17VSb, while the highest evenness was at MH12VSb (Table 5.3).

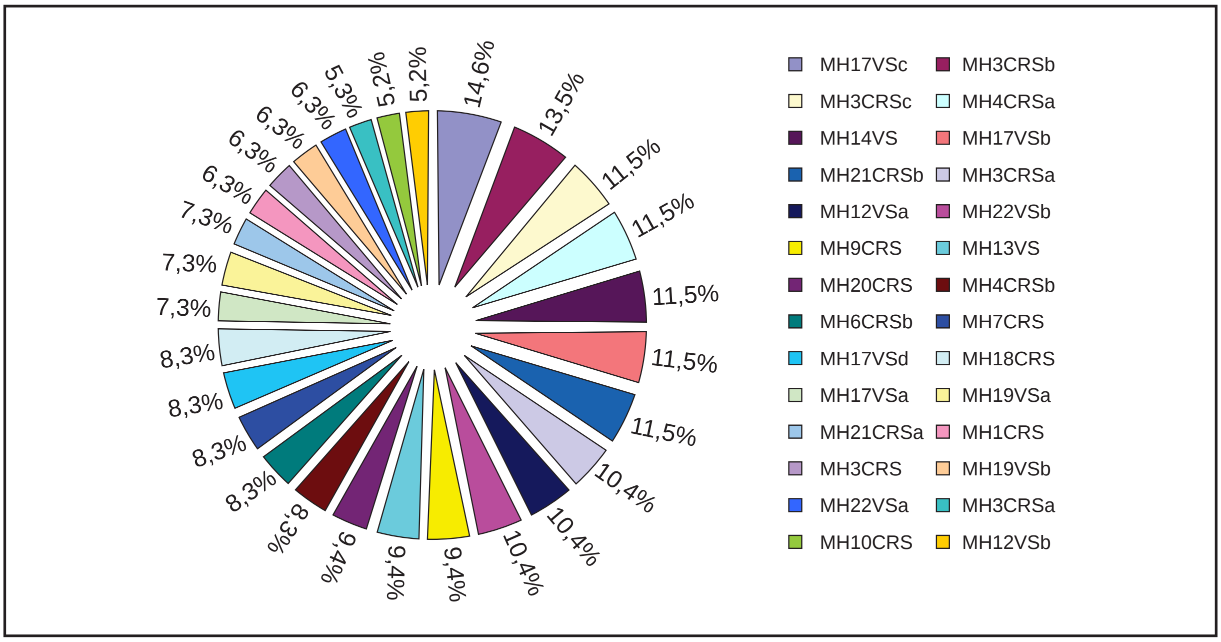


**Figure 5.4: Species Richness (SR) of the microcatchment watershed sites at Mharib during the autumn survey (December 2006).**

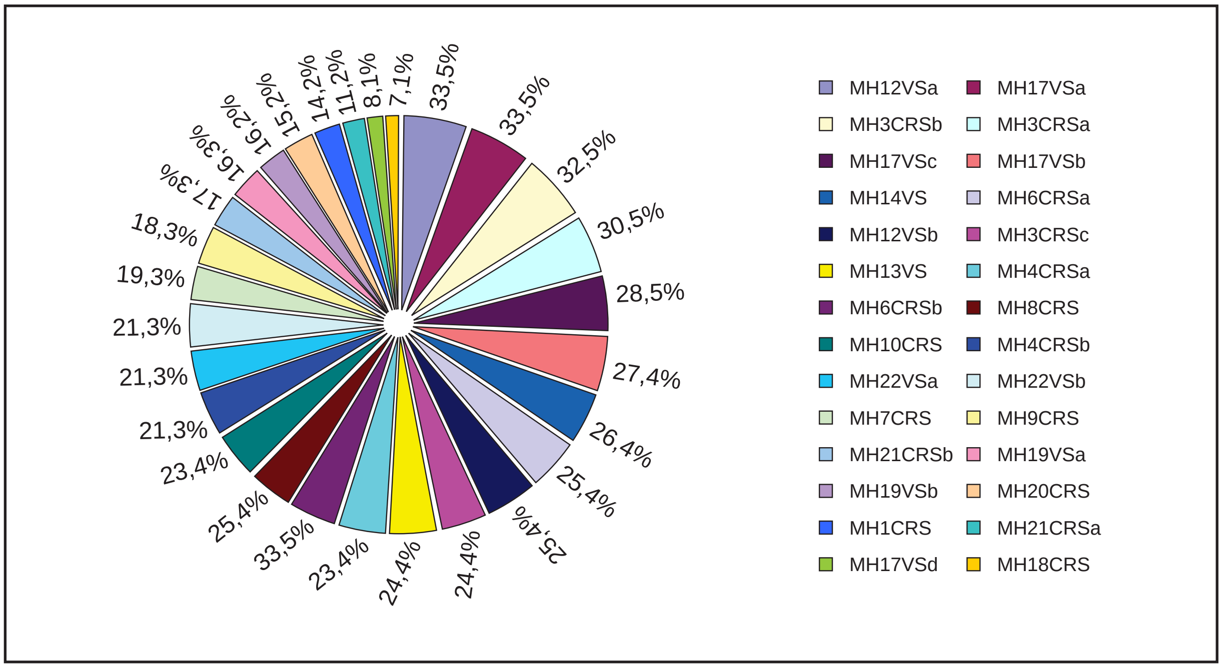


**Figure 5.5: Species Richness (SR) of the microcatchment watershed sites at Mharib during the spring survey (April 2007).**

**Table 5.3. Shannon–Wiener Diversity Index (SDI) and Shannon's Equitability (EH) of the Mharib sites.**

| Site | December 2006 | | April 2007 | |
|---|---|---|---|---|
| | SDI | EH | SDI | EH |
| MH1CRS | 1.02 | 0.57 | 1.25 | 0.48 |
| MH3CRSa | 1.17 | 0.51 | 2.16 | 0.63 |
| MH3CRSb | 0.91 | 0.36 | 2.27 | 0.65 |
| MH3CRSc | 1.27 | 0.55 | 2.32 | 0.73 |
| MH4CRSa | 1.29 | 0.54 | 2.33 | 0.74 |
| MH4CRSb | 0.52 | 0.25 | 2.36 | 0.78 |
| MH6CRSa | 1.05 | 0.65 | 2.05 | 0.64 |
| MH6CRSb | 1.00 | 0.48 | 2.23 | 0.71 |
| MH7CRS | 0.78 | 0.37 | 2.29 | 0.78 |
| MH8CRS | 1.12 | 0.63 | 2.52 | 0.81 |
| MH9CRS | 0.84 | 0.38 | 2.17 | 0.73 |
| MH10CRS | 0.80 | 0.50 | 1.63 | 0.52 |
| MH12VSa | 1.31 | 0.57 | 2.51 | 0.72 |
| MH12VSb | 1.19 | 0.74 | 2.48 | 0.77 |
| MH13VS | 1.03 | 0.47 | 2.36 | 0.74 |
| MH14VS | 1.38 | 0.58 | 2.33 | 0.72 |
| MH17VSa | 1.26 | 0.65 | 2.63 | 0.75 |
| MH17VSb | 1.45 | 0.61 | 2.46 | 0.75 |
| MH17VSc | 1.19 | 0.44 | 2.02 | 0.61 |
| MH17VSd | 1.04 | 0.50 | 1.04 | 0.50 |
| MH18CRS | 0.91 | 0.47 | 0.91 | 0.47 |
| MH19VSa | 0.82 | 0.42 | 2.25 | 0.81 |
| MH19VSb | 0.75 | 0.42 | 2.25 | 0.81 |
| MH20CRS | 0.98 | 0.45 | 1.56 | 0.58 |
| MH21CRSa | 1.13 | 0.58 | 1.48 | 0.53 |
| MH21CRSb | 1.11 | 0.46 | 1.69 | 0.60 |
| MH22VSa | 1.05 | 0.59 | 2.33 | 0.77 |
| MH22VSb | 1.35 | 0.58 | 2.28 | 0.75 |

In the spring survey, the highest SDI was at MH19VSa (Table 5.3). This site had the second highest evenness after MH19VSb, and contained 27 plant species where 15 had similar existence percentage (around 40% of individuals). MH19VSb contained 16 species (the same SR as MH19VSa), but had very close percentages. The highest occupation was for *T. torulosa* and *G. micrantha* (13.5% each) and *Ha. eigü* (11%), with the rest in the range 3–9%. Such close percentages result in high EH. MH18CRS had the lowest SDI and hence the lowest evenness, indicating that was the more disturbed habitat among the other sub-watersheds.

### Annuals–perennials ratio (AP-ratio)

The different plant species recorded in the MH22VSb site in the two survey dates were classified according to their life-cycle or description as annuals or perennials. The AP-ratio was calculated (Table 5.4). The increase in annuals in the spring compared to autumn survey was mainly due to the growth of the annuals that increased SR by 2–5-fold in some sites. This is due to the fact that perennials were already there at the two survey dates; however, annuals require cold and rain during winter to germinate and grow. The diversity of the dry areas is mainly due to the presence of annuals (not perennials) as they are larger and fluctuate in numbers due to the climatic conditions, mainly rain. Such results are consistent with those of (Aronson and Shmida 1992) and (Russi et al. 1992).

A total of 90 plant species were recorded in the present study. The numbers of annuals and perennials encountered were 64 (71%) and 26 (29%), respectively.

The dry environment in the study area resulted in more growth of annuals than perennials, as annuals can withstand dry conditions better due to their short life-cycle. Unfortunately the annuals also expose the soils to erosion by leaving the ground bare. Similarly, (Batanouny 1973) found that perennial palatable plants, which protect the soil best, are grazed and replaced by ephemerals which dry up and produce less forage, and that their roots do not protect the soil. Glover (2003) found that annual crops inefficiently utilize water and nutrients and that these result in the degradation of soil and water quality. He concluded that with a high proportional allocation of biomass to shoots, annuals grew more rapidly than perennials to complete their life-cycles before soils became very dry. Rapid growth by annuals is associated with both shallow rooting and correspondingly shallow soil-water utilization (Holmes and Rice, 1996).

### Plant families

Plant species recorded in the 28th sub-watershed (Table 5.5) were classified according to their families (Zohary 1966; Al-Eisawi 1998)). A total of 24 different families and 87 species were recorded, in the following proportions: Asteraceae and Poaceae families (16% each); 15% Brassicaceae, Caryophyllaceae, and Liliaceae (8% each); Chenopodiaceae (7%); Papilionaceae (6%); and the rest were distributed among other families with small percentages of 1–3%.

In April 2007, 19 families were recorded compared to 12 in December 2006. In April 2007, Poaceae and Asteraceae families recorded the highest number of species (19%), followed by Brassicaceae (12%) and Chenopodiaceae (10%). In December 2006, Asteraceae had the highest plant percentage (20%), followed by Poaceae and Chenopodiaceae (19% each).

### Forbs/herbs species

The recorded plant species (Table 5.5) were divided into 66 species of herbs (comprising 75.9%), 15 graminoides (17.2%), and six shrubs (6.9%). Graminoids' water requirements are higher than for herbs (all plant species except grasses), thus herbs can survive desert conditions.

**Table 5.4. Species Richness (SR) and Annuals–Perennials ratio (AP-ratio) of different plant species recorded in MH22VSb for the two survey dates.**

| | December 2006 | | April 2007 | |
|---|---|---|---|---|
| **Site** | **SR** | **AP-ratio** | **SR** | **AP-ratio** |
| MH1CRS | 6 | 0.33 | 14 | 0.86 |
| MH3CRSa | 10 | 0.60 | 30 | 0.40 |
| MH3CRSb | 13 | 0.67 | 32 | 0.50 |
| MH3CRSc | 11 | 0.70 | 24 | 0.79 |
| MH4CRSa | 11 | 0.64 | 23 | 0.83 |
| MH4CRSb | 8 | 0.63 | 21 | 0.76 |
| MH6CRSa | 5 | 0.60 | 25 | 0.80 |
| MH6CRSb | 8 | 0.75 | 23 | 0.86 |
| MH7CRS | 8 | 0.75 | 19 | 0.79 |
| MH8CRS | 6 | 0.50 | 23 | 0.83 |
| MH9CRS | 9 | 0.78 | 18 | 0.89 |
| MH10CRS | 5 | 0.60 | 23 | 0.83 |
| MH12VSa | 10 | 0.70 | 33 | 0.79 |
| MH12VSb | 5 | 0.60 | 25 | 0.72 |
| MH13VS | 9 | 0.67 | 24 | 0.71 |
| MH14VS | 11 | 0.73 | 26 | 0.69 |
| MH17VSa | 7 | 0.71 | 33 | 0.70 |
| MH17VSb | 11 | 0.73 | 27 | 0.70 |
| MH17VSc | 14 | 0.67 | 28 | 0.71 |
| MH17VSd | 8 | 0.50 | 8 | 0.50 |
| MH18CRS | 8 | 0.71 | 7 | 0.71 |
| MH19VSa | 7 | 0.57 | 16 | 0.69 |
| MH19VSb | 6 | 0.67 | 16 | 0.75 |
| MH20CRS | 9 | 0.56 | 15 | 0.73 |
| MH21CRSa | 7 | 0.71 | 11 | 0.69 |
| MH21CRSb | 11 | 0.64 | 17 | 0.65 |
| MH22VSa | 6 | 0.67 | 21 | 0.81 |
| MH22VSb | 10 | 0.70 | 21 | 0.71 |

Herbs are found in larger numbers than grasses. Our study area is dryland with a long history of disturbances that have resulted in low vegetation cover, and few species (mainly unpalatable) have survived and still occupy the area. Thus, there is a small number (5% of recorded species) of shrubs. The seeds of weed species are generally aggregated around the mother plant; however, the quantity of seeds in a particular area depends on numerous factors such as the shape and the size of the parent plant, the size and shape of the seeds themselves, and the activity of

**Table 5.5. List of plant species recorded in the Mharib intervention area arranged according to family, growth habit, and life duration.**

| Family | Growth habit | Life duration | Species |
|---|---|---|---|
| Araceae | Herb | Perennial | Biarum angustifol L. |
| Asteraceae (Compositae) | Herb | Annual | Aaronsohnia factorovskyi Warb. & Eig |
| | | | Anthemis haussknechtii Boiss. & Reut. |
| | | | Calendula arvensis L. |
| | | | Centaurea pallescens Delile |
| | | | *Filago contracta* (Boiss.) Chrtek and Holub |
| | | | Filago desertorum Pomel |
| | | | Gymnarrhena micrantha Desf. |
| | | | Koelpinia linearis Pall. |
| | | | Lasiopogon muscoides (Desf.) DC. |
| | | | Notaobasis syriaca (L.) Cass. |
| | | | Rhagadiolus stellatus (L.) Gaertn. |
| | | Perennial | Achillea fragrantissima (Forssk.) Sch.Bip. |
| | | | Achillea santolina L. |
| | | | Scorzonera schweinfurthii (Boiss) Thiébaut |
| Boraginaceae | Herb | Annual | Gastrocotyle hispida (Forssk.) Bunge |
| | | | Lappula spinocarpos (Forssk.) Asch. |
| Brassicaceae (Cruciferae) | Herb | Annual | Alyssum damascenum Boiss. & Gaill |
| | | | Capsella bursa-pastoris (L.) Medik |
| | | | Cardaria draba (L.) Desv. |
| | | | Chorispora L. |
| | | | Dipoltaxis erucoides (L.) DC. |
| | | | Eruca sativa Mill. |
| | | | Hirschfeldia incana (L.) Lagr.-Foss. |
| | | | Malcolmia conringiodes Boiss. |
| | | | Raphanus aucheri Boiss. |
| | | | Sinapis arvensis L. |
| | | | Sisymbrium irio L. |
| | | | *Torularia torulosa* (Desf.) O. E. Schulz |
| | Semi-shrub | Perennial | Ankyropetalum gypsophiloides Fenzel |
| Caryophyllaceae | Herb | Annual | Gypsophila pilosa Huds. |
| | | | Herniaria hirsuta L. |
| | | | *Holostium glutinosum* (M.Bieb.) Fisch. & C.A.Mey |
| | | | Silene coniflora Otth. |
| | | | Silene conoidea L. |

**Table 5.5. (Continued).**

| Family | Growth habit | Life duration | Species |
|---|---|---|---|
| | | | *Spergularia rubra* (L.) J. & C.Presl |
| | | | Vaccaria pyramidata Medik. |
| Chenopodiaceae | Herb | Annual | Bassia muricata (L.) Asch. |
| | | | Chenopodium album L. |
| | Shrub | Perennial | Anabasis syriaca Iljin |
| | | | Hammada eigii Iljin |
| | | | Atriplex halimus L. |
| | | | Salsola vermiculata L. |
| Cistaceae | Herb | Annual | Helianthemum ledifolium (L.) Miller |
| Cyperaceae | Graminoids | Annual | Carex spp. |
| Euphorbiaceae | Herb | Annual | Euphorbia peplus L. |
| Fumariaceae | Herb | Annual | Fumaria densiflora DC. |
| | | | Hypecoum procumbens L. |
| Geraniaceae | Herb | Perennial | Erodium hirtum Willd |
| Iridaceae | Herb | Perennial | Gynandiris sisyrinchium (L.) Parl |
| Liliaceae | Herb | Perennial | Allium desertorum Forssk. |
| | | | Allium erdelii Zucc. |
| | | | Allium staminum L. |
| | | | Colchicum tunicatum Feinbrun |
| | | | *Gagea chlorantha* (M.Bieb.) Schult. & Schult.f. |
| | | | *Gagea reticulate* (Pall.) Schult. & Schult.f. |
| | | | Leopoldia longipes (Boiss) Losinsk. |
| Malvaceae | Herb | Annual | Malva praviflora L. |
| | | | Malva sylvestris L. |
| Papaveraceae | Herb | Annual | Roemeria hybrida (L.) DC. |
| Papilionaceae | Herb | Annual | Astragalus corrugatus Bertol. |
| | | | Astragalus cruciatus Link |
| | | | Onobrychis crista-galli (L.) Lam |
| | | | Vicia peregrina L. |
| | | | Trigonella stellata Forsk. |
| Plantaginaceae | Herb | Annual | Plantago coronopus L. |
| Poaceae | Graminoids | Annual | Bromus lanceolatus Roth |
| | | | Bromus madritensis sub sp. Delilei |
| | | | Catapodium rigidum (L.) C.E.Hubb |
| | | | *Crithopsis delileana* (Schult. & Schult.f.) Roshev. |

**Table 5.5. (Continued).**

| Family | Growth habit | Life duration | Species |
|---|---|---|---|
| | | | Echinaria capitata (L.) Desf. |
| | | | Eremopyrum bonaepartis (Sprengel) Nevski |
| | | | Hordeum glaucum Steudel |
| | | | Phalaris minor Retz |
| | | | Poa sinaica Steud |
| | | | Rostraria berythea L. |
| | | | *Schismus barbatus* (Loefl. ex L.) Thell. |
| | | | Stipa capensis Thunb. |
| | | Perennial | Koeleria cristata (L.) Bertol. |
| | | | Poa bulbosa L. |
| Polygonaceae | Herb | Annual | Rumex cyprius Murb. |
| Portulacaceae | Herb | Annual | Portulaca oleracea L. |
| Primulaceae | Herb | Annual | Androsace maxima L. |
| Ranunculaceae | Herb | Annual | Adonis dentata Del. |
| | | | Ceratocepahala falcata (L.) Pers. |
| Umbelliferae | Herb | Annual | Tordylium aegyptiacum (L.) Lam. |
| Zygophyllaceae | Shrub | Perennial | Peganum harmala L. |

the seed dispersal agents (e.g. wind and animals). For some species, seed survival in soils is rather short and most will germinate in the first year (Holmes and Rice, 1996).

**Flora map**

The plant species were mapped (Annexes 1.7–1.10) using characteristic species for each sub-watershed (to represent the particular type of species likely to be found within that community).

## 5.3 Impact of microcatchments water harvesting on soil seed bank

### 5.3.1 Introduction

According to (Roberts 1981), the term 'soil seed bank' designates the viable seed reservoir present in the soil and on its surface. (Simpson et al. 1989) defined the soil seed bank as the total amount of viable seeds (including vegetative propagules) found in the soil. Soil seed banks play a critical role in vegetation maintenance, succession, ecosystem restoration, differential species management, and conservation of genetic variability (Lemenih and Teketay, 2006). Use of soil seed bank in vegetation succession management is acknowledged as a low-cost restoration technique, since it solves many of the problems associated with collecting, storing, and sowing seeds, as well as transplanting individual seedlings raised in a nursery (Van der Valk and Pederson, 1989 as cited by Lemenih and Teketay, 2006). Assessment of the soil seed bank of a rangeland will reflect the potential of native vegetation cover of this rangeland, if the basic element of life (water) is provided.

### 5.3.2 Materials and methods

An experiment was conducted at Mharib intervention site located near Mharib village. The site area was around 7.2 ha and characterized by two slopes, gentle (< 5%) and moderate (8–12%). The Vallerani implement was used to form contour ridges in two shapes: continuous and intermittent. The farmers' traditional method of making furrows with a chisel plow disc was also used. *Atriplex halimus* shrubs were planted in the contour ridges of both the Vallerani machine and the traditional furrows with fixed distances (6 m for all treatments). Barley was planted in the experiment site using the local farmers' traditional planting method with 50 kg seeds/ha. The implementation started at the end of December 2005, after the rainy season began.

**Treatments and experimental design:** The experiment consisted of two main land slopes, slope 1 (S1: < 5%), and slope 2 (S2: 8–12%), and the sub-treatments in each slope were:

T1: WH with Vallerani intermittent contour ridges (CRVI), within catchment area (CRVIC)
T2: WH with CRVI, within ridges (CRVIW)
T3: WH with Vallerani continuous contour ridges (CRVC), within catchment area (CRVCC)
T4: WH with CRVC, within ridges (CRVCW)
T5: WH with traditional contour ridges (CRTP), within catchment area (CRTPC)
T6: WH with CRTP, within ridges (CRVCW)
T7: barley plantation (BP)
T8: control, with no intervention and no grazing (CIG)
T9: control, outside the intervention area, but protected from grazing (to study the effect of protection against the intervention plus protection)

Three transects were laid down per slope-type per sub-treatment. Fifteen composite soil samples were taken at 4 cm depth per transect for the soil seed bank analysis. Three soil samples were taken per transect for the soil analysis. The experiment was replicated three times, which resulted in 54 plots (sizes 0.05–0.4 ha). The data was analyzed using repeated measure arrangements.

**Sampling procedure:** Three 50-m-long transects were laid down randomly along each plot and five quadrats of 1 $m^2$ were marked at 10-m intervals on the transect; then a 5-cm diameter and 20-cm-long cylindrical tube was used to sample the soil to a depth of 0–4 cm from each corner of the quadrat. The four samples were mixed to form one composite soil sample per quadrat, with a soil volume of 314 $cm^3$ for each quadrat

(Figure 5.6). The soil was placed in labeled plastic bags according to plot number and quadrat number. Thus there were 15 composite soil seed bank samples from each plot with a total soil volume of 4710 $cm^3$, which is 7.8 times greater than the soil sample volumes suggested by (Roberts 1981) and (Ball and Miller 1989). A total of 810 soil seed bank samples were taken from all 54 plots. The sampling was conducted twice: in December 2006 and June 2007.

Consequently, a total of 1620 soil samples were collected for the assessment of the soil seed bank. Soil samples were placed in a large plastic bucket and washed with tap water, then sieved through 250-μm mesh, after removing stones. The soil debris was placed on paper and left to dry in the air. The dry soil debris were put back in plastic bags and stored at 4°C for further seed separation. The seeds were separated by hand, using (9×) magnifying lenses.

The separated seeds were identified (to species level when possible) using seed samples, as a key, collected from the field from previously identified plant species. Seed viability was determined by applying gentle pressure to each seed with forceps, and seeds resisting pressure were recorded as 'apparently viable', as used by several workers (Hayashi et al., 1978; Ball and Miller, 1989). For the purpose of this study, a determination of apparent viability was sufficient to make appropriate study comparisons. Seeds were counted and kept in aluminum bags in a refrigerator at 4°C.

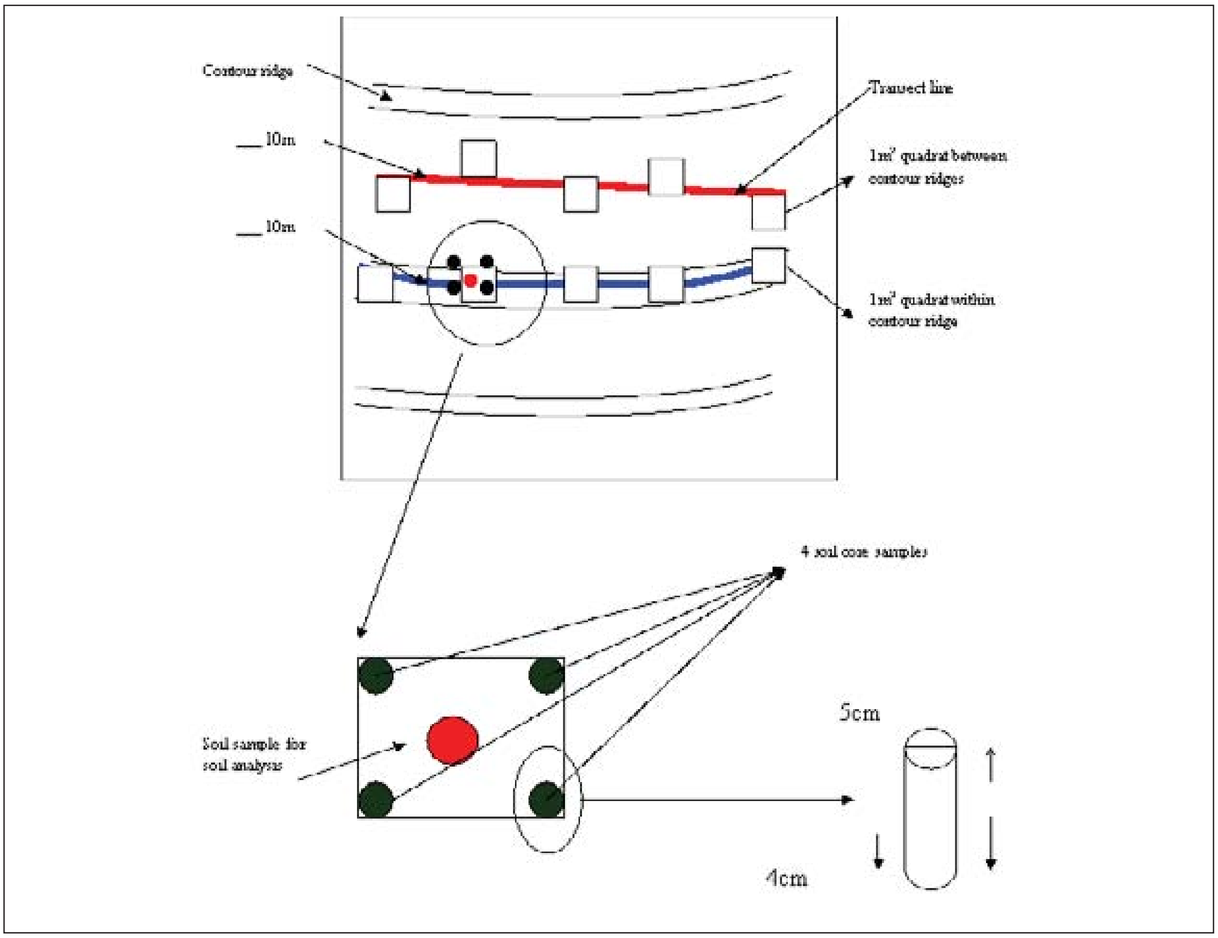


**Figure 5.6: Sampling technique for soil seed bank analysis.**

**Table 5.6. Three-way interaction effect of slope, dates, and WH interventions on seeds extracted from the soil.**

| Slope | Date | WH Intervention | Mean seed number/m² |
|---|---|---|---|
| < 5% | December 2006 | $T^1$: CRVIC | 1637 gh* |
| | | $T^2$: CRVIW | 2959 e |
| | | $T^3$: CRVCC | 628 hij |
| | | $T^4$: CRVCW | 2939 e |
| | | $T^5$: CRTPC | 1777 fg |
| | | $T^6$: CRTPW | 4211 bcd |
| | | $T^7$: Bp | 694 hij |
| | | $T^8$: CIG | 562 ij |
| | | T9: C-outside the intervention | 155 j |
| | June 2007 | $T^1$: CRVIC | 802 ghij |
| | | $T^2$: CRVIW | 4115 bcd |
| | | $T^3$: CRVCC | 1010 ghij |
| | | $T^4$: CRVCW | 4764 abc |
| | | $T^5$: CRTPC | 1418 ghi |
| | | $T^6$: CRTPW | 3748 cde |
| | | $T^7$: Bp | 592 hij |
| | | $T^8$: CIG | 523 ij |
| | | T9: C-outside the intervention | 432 ij |
| 8–12% | December 2006 | $T^1$: CRVIC | 809 ghij |
| | | $T^2$: CRVIW | 5395 a |
| | | $T^3$: CRVCC | 782 ghij |
| | | $T^4$: CRVCW | 3369 de |
| | | $T^5$: CRTPC | 880 ghij |
| | | $T^6$: CRTPW | 2723 ef |
| | | $T^7$: Bp | 969 ghij |
| | | $T^8$: CIG | 984 ghij |
| | | T9: C-outside the intervention | 143 j |
| | June 2007 | $T^1$: CRVIC | 875 ghij |
| | | $T^2$: CRVIW | 4858 ab |
| | | $T^3$: CRVCC | 867 ghij |
| | | $T^4$: CRVCW | 4789 abc |
| | | $T^5$: CRTPC | 1063 ghij |
| | | $T^6$: CRTPW | 4336 abcd |
| | | $T^7$: Bp | 1067 ghij |
| | | $T^8$: CIG | 980 ghij |
| | | T9: C-outside the intervention | 450 ij |

Note: * Values followed by the same letter are not significantly different at $P < 0.05$.

### 5.3.3 Results and discussion

**Size of the soil seed bank**

Analysis of variance (ANOVA) was performed for mean number of seeds extracted from the soil (Annex 1.11). The three-way interaction of the effect of slope, sampling date, and WH on seed number extracted from soil was determined (Table 5.6). The mean soil seed numbers in June 2007 of 17 404 and 19 285 seeds/m$^2$ in the gentle and moderate slopes, respectively, were about 11 and 17% higher than for the respective December 2006 values of 15562 and 16054 seeds/m$^2$.

The highest number of seeds recorded in June is related to the fact that different herbaceous plants shed their seeds during May–June every year and the seeds fall to the ground and enrich the soil seed bank (Thompson and Grim, 1979; Garwood, 1989; Russi et al., 1992). The number of annual plants increased in summer after the rainy season; they shed their seeds in soil and so enriched the soil seed bank. Annuals avoid the seasonal drought; they complete their life-cycle by producing and dispersing matured seeds at the beginning of the hot dry season. The seeds remain as a 'seed bank' in the soil or amidst the dry remains of dead mother plants, where they can be dispersed over many years (Shmida and Burgess, 1988; Gutterman, 1993). The perennials are always there and their seed numbers increase due to shedding from mother plants. Perennials allocate a higher proportion of their total biomass to shoots to sustain rapid whole-plant growth rates, as reflected in less of their seeds produced than of annuals.

Of the mean soil seed number/m$^2$, 67–73% was captured within the contour ridges, with 15–26% in the catchment area. Only 3–6% was found in the barley intervention area, 3–6% was found in the CIG control treatment, and 1–2.5% was found in the control treatment outside the intervention area. The highest seed number (38–55%) was within the Vallerani contour ridges, and the traditional plowing captured 17–23% of soil seeds. The significant increase in the soil seed bank due to using WH techniques implied that reliance on the soil seed bank for the recovery of native flora on fields abandoned after a number of years of continuous conservation may be successful. Contours create a suitable climate for the plants to grow and form seeds, and also form a sink for seeds moving down the slope from the catchment area after rain. Water will settle in the contours with the soil and the seeds it carries, as a result the soil seed bank will be larger in contours than other parts of the catchment area. Native vegetation will benefit from the water that the contours provide and increase the cover percentage and SR. Even the native plants that are well adapted to hot and dry conditions will usually benefit from supplemental water provided by microcatchments and produce more flowers and seeds than plants in open areas without treatments (Van der Valk and Pederson, 1989; Fidelibus and Bainbridge, 1994; Suleman et al., 1995; Bainbridge, 2003; Yan et al., 2006).

Vallerani intermittent contour ridges (CRVI) intervention captured a higher number of seeds/m$^2$ (19–35% of soil seeds) within the ridges, whereas Vallerani continuous contour ridges (CRVC) captured 19–27%. The catchment area of the Vallerani interventions recorded 9–15% of the soil seeds compared with 5.5–11% recorded for traditional plowing. The CRVI catchment area captured 5–11% of the seed number and the CRVC catchment captured 4–6%. The highest mean seed number/m$^2$ was within the ridges of the Vallerani intermittent contour ridges treatment in December 2006 (5395 seeds/m$^2$), which was not significantly different from those recorded within the ridges of the CRVI intervention; or within the ridges of the CRVC and traditional contour ridges interventions in June 2007 (4858, 4789, and 4336 seeds/m$^2$, respectively) in the moderate slope. Moreover, values for the moderate slope did not significantly differ from the amount of seeds recorded within the ridges of the gentle slope of the CRVC intervention (4764 seeds/m$^2$) recorded in December 2006.

The higher value of mean seed number/m$^2$ in the CRVI over the other structures was a result of the deeper contours made by the Vallerani machine compared to traditional plowing. CRVI gave a higher seed number/m$^2$ over the CRVC, possibly due to the smaller basins made by CRVI, which enabled retention of a greater amount of soil moisture. This is consistent with results of Suleman et al. (1995), who found that soil moisture can be significantly increased with microcatchments of 4 and 5 m in length. This supports the positive effect of the intermittent structure of the contours that have smaller dimension than continuous structures.

The amount of seeds in the soil seed bank in the barley plantation did not significantly differ from that for either of the control treatments. The highest mean seed number was for the barley intervention. The lowest was for the control outside the intervention area, which only captured 3% of seeds (423 and 450 seeds/m$^2$ for gentle and moderate slopes, respectively, in June 2007) compared to CRVI.

Cultivation affects the soil seed bank by damaging or breaking seeds directly, or by bringing buried seeds to the surface and exposing them to predators, desiccating winds, high temperature, direct solar radiation, or inducing them to germinate and die – as a result the soil seed bank under barley was smaller than for other treatments. Such results agree with other findings (Bowers, 1987; Bainbridge, 2003; Lemenih and Teketay, 2006) showing that such environmental factors as high temperature and direct solar radiation on bare soils of farm fields may induce rapid loss of seed viability and consequently reduce woody species composition in the soil seed bank. Cultivation moved the layer of soil of about 5–10-cm depth upward and seeds in the soil were subjected to high light and temperature, in addition to loss of soil moisture – such conditions result in the death of a large amount of seeds.

Protection is not the only solution for rangeland rehabilitation, as shown by the size of the soil seed bank in the control outside the intervention area but protected from grazing; this soil seed bank was smaller than for the control treatment inside the intervention area which had the benefit of both the WH intervention and protection from grazing. Although the control treatment inside the intervention area had no contour structure, it benefitted from the catchment areas of the other treatments as it was randomly distributed between them.

The average number of seeds in the soil seed bank during December 2006 (Table 5.7) ranged from 16 seeds/m$^2$ for *Bromus lanceolatus* Roth., *Capsella bursa-pastoris* (L.) Medik, and *Plantago* coronopus L. to 206 165 seeds/m$^2$ for *Herniaria hirsuta* L. For samples collected in June 2007 (Table 5.8) the soil seed bank ranged from 31 seeds/m$^2$ for *Ankyropetalum gypsophiloides* Fenzel to 128 254 seeds/m$^2$ for *He. hirsuta.* Clearly *He. hirsuta* was the major component of the soil seed bank during the study period: representing 39 and 48% of the total and the annual soil seed banks, respectively, in December 2006 samples; and correspondingly 22 and 25% in June 2007. *Schismus barbatus* (Loefl. ex L.) Thell. ranked third (54 510 seeds/m$^2$) during December 2006, and formed 10 and 13% of the total and annual soil seed banks, respectively; it ranked second (77 927 seeds/m$^2$) during June 2007 and formed 13 and 15%, respectively, of the total and annual soil seed banks.

The high soil seed bank of *He. hirsuta* and *Sc. barbatus reflects* the dominance of the Caryophyllaceae and Poaceae families, which produce large numbers of very small seeds shed from mother plants (Gutterman 1993). Large numbers of such seeds moved to soil cracks and under

**Table 5.7. Average seed number (no./m²) of annual and perennial plant species in the soil seed bank during December 2006.**

| Species (annuals) | Average seed (no./m²) | Species (annuals) | Average seed (no./m²) |
|---|---|---|---|
| Herniaria hirsuta L. | 206 165 | Poa sinaica Steud. | 267 |
| Gymnarrhena micrantha Desf. | 79 311 | Eremopyrum bonaepartis (Sprengel) Nevski | 252 |
| *Schismus barbatus* (Loefl. ex L.) Thell. | 54 510 | Rumex cyprius Murb. | 236 |
| Filago desertorum Pomel | 33 215 | Alyssum damascenum Boiss. & Gaill | 236 |
| *Torularia torulosa* (Desf.) O. E. Schulz | 18 196 | Roemaria hybrida (L.) DC. | 220 |
| Androsace maxima L. | 11 434 | Trigonella stellata Forskal | 220 |
| Hordeum vulgare L. | 3397 | Astragalus spp. | 204 |
| Hordeum glaucum Steud. | 3366 | Ankyropetalum gypsophiloides Fenzel | 189 |
| Eruca spp. | 2501 | Malva sylvestris L. | 189 |
| Ceratocepahala falcata (L.) Pers. | 2280 | Fumaria densiflora DC. | 173 |
| Helianthemum ledifolium (L.) Miller | 2076 | Sisymbrium irio L. | 173 |
| Aaronsohinia factorovshyi Warb. & Eig | 1746 | Vaccaria pyramidata Medik. | 142 |
| Sinapis arvensis L. | 1714 | Phalaris minor Retz | 110 |
| Lasiopogon muscoides (Desf.) DC. | 1526 | Gypsophila pilosa Huds. | 94 |
| Malcolmia conringiodes Boiss | 1258 | Echinaria capitata (L.) Desf. | 94 |
| Portulaca oleracea L. | 1038 | Asperugo procumbence L. | 79 |
| Gynandiris sisyrinchium (L.) Parl | 802 | Tordylium aegyptiacum (L.) Lam. | 63 |
| Anthemis spp. | 535 | Hypecoum procumbens L. | 47 |
| Adonis dentata Del | 472 | Silene conoides L. | 47 |
| Hirschfeldia incana (L.) Lagr.-Foss. | 456 | Rostraria berythea L. | 47 |
| Chenopodium album L. | 330 | Bromus lanceolatus Roth | 16 |
| Euphorbia peplus L. | 315 | Capsella bursa-pastoris (L.) Medik | 16 |
| Astragalus cruciatus Link. | 283 | Plantago sp. | 16 |
| Poa bulbosa L. | 40 874 | Leopoldia longipes (Boiss) Losinsk. | 409 |

**Table 5.7. (Continued).**

| Species (annuals) | Average seed (no./m²) | Species (annuals) | Average seed (no./m²) |
|---|---|---|---|
| Anabasis syriaca Iljin | 37 792 | Atriplex halimus L. | 157 |
| Hammada eigii Iljin | 6763 | Allium erdelii Zucc. | 110 |
| Achillea fragrantissima (Forskal) Schultv Bip | 2689 | Gagea spp. | 63 |
| Bellevalia spp. | 2265 | Erodium hirtum Willd. | 31 |
| Allium desertorum Forssk. | 2233 | Peganum harmala L. | 31 |
| Astragalus cruciatus | 1478 | Cardaria draba (L.) Desv. | 16 |

stones and were protected from wind dispersal, and so became assets in the soil seed bank. The greater size of the soil seed bank for some species such as *He. hirsuta* and *G. micrantha* is mainly due to the fact that such plants are characterized by a long delay in dispersal (Zohary, 1962).

These seeds mature in May–June, but are found in largest numbers in October. Such seeds are protected by the dry body of the mother plant, a survival mechanism of the dryland species for protection against being eaten by ants or dispersed by wind. So during October–November when few rain drops fall on the soil surface a micro-habitat is created for the seeds to leave the mother plant for the soil surface ready for germination. Not all seeds are shed by the mother plant, a reasonable percentage are kept for the next season in the case of rainfall being insufficient for growth after germination.

The majority of the identified seeds were annuals; around 82% in December 2006, and 90% in June 2007 (Tables 5.7 and 5.8). Seed of perennial species increased by 41% in June 2007 compared with December 2006. Poa bulbosa formed the highest proportion of the soil seed bank (43% in June 2007 and 37% in December 2006). Two species recorded in June 2007 (*Cardaria draba* (L.) *Desv. and Peganum harmala* L.) were not recorded in December 2006; and two species, K*oeleria cristata* (L.) Pers. and *Achillea sp*., were not found at all.

The highest seed density in the soil seed bank was recorded for He. hirsuta (48% in December 2006 and 25% in June 2007) for all interventions, except for both of the control treatments.

For control treatments, whether inside or outside the interventions, the highest soil seed banks were for *P. bulbosa* with 43 and 37% in December 2006 in June 2007, respectively, and for *G. micrantha* with 18 and 7%, respectively (Table 5.9).

The highest average seed number (26% of the total soil seed bank) was obtained within the ridges of the WH with CRVI, followed by the traditional contour ridges intervention (20%), then for CRVC (18%). The soil seed bank was 50–60% higher within the contour ridges compared to that in the catchment area. The barley plantation showed higher seed numbers for *He. hirsuta* (6% of the total soil seed bank); however, the highest soil seed bank was for *P. bulbosa* (1%) in the control treatment with no intervention and no grazing. The soil seed bank in the control (outside the intervention area) had the lowest soil seed bank, mainly of *G. micrantha* and *represented* only 0.13% of the soil seed bank.

**Table 5.8. Average seed number (no./m²) of annual and perennial plant species in the soil seed bank during June 2007.**

| Species (annuals) | Average seed (no./m²) | Species (annuals) | Average seed (no./m²) |
|---|---|---|---|
| Herniaria hirsuta L. | 128 254 | Gynandiris sisyrinchium (L.) Parl. | 1007 |
| Schismus barbatus (Loefl. ex L.) Thell. | 77 927 | Sinapis arvensis L. | 865 |
| Torularia torulosa (Desf.) O. E. Schulz | 71 684 | Anthemis spp. | 771 |
| Poa sinaica Steud. | 44 366 | Euphorbia peplus L. | 755 |
| Filago desertorum Pomel | 41 614 | Fumaria densiflora DC. | 755 |
| Gymnarrhena micrantha Desf. | 35 055 | Astragalus cruciatus Link. | 723 |
| Ceratocepahala falcata (L.) Pers. | 24 251 | Rumex cyprius Murb. | 661 |
| Androsace maxima L. | 15 082 | Aaronsohinia factorovshyi Warb. & Eig | 661 |
| Hirschfeldia incana (L.) Lagr.-Foss. | 11 559 | Chenopodium album L. | 488 |
| Hordeum glaucum Steud. | 8335 | Astragalus spp. | 440 |
| Malcolmia conringiodes Boiss | 7911 | Rhagadiolus stellatus (L.) Gaertner | 346 |
| Eruca spp. | 5945 | Hypecoum procumbens L. | 283 |
| Sisymbrium irio L. | 5174 | Trigonella stellata Forskal | 267 |
| Rostraria berythea L. | 5017 | Plantago coronopus L. | 252 |
| Dipoltaxis erucoides (L.) DC. | 3947 | Chorispora spp. | 252 |
| Alyssum damascenum Boiss. & Gaill | 2689 | Stipa capensis Thunb. | 236 |
| Bassia muricata (L.) Ascher-son | 2626 | Bromus madritensis sub sp. delilei | 236 |
| Roemaria hybrida (L.) DC. | 2422 | Asperugo procumbence | 204 |
| Hordeum vulgare L. | 2391 | Echinaria capitata (L.) Desf. | 204 |
| Silene conoides L. | 2375 | Portulaca oleracea L. | 189 |
| Lasiopogon muscoides L. | 2328 | Vaccaria pyramidata Medik. | 173 |
| Helianthemum ledifolium (L.) Miller | 2202 | Notaobasis syriaca (L.) Cass. | 142 |
| Adonis dentata Del | 1730 | Carex L. | 142 |
| Malva sylvestris L. | 1683 | Spergularia rubra (L.) J. & C. Presl. | 142 |

**Table 5.8. (Continued).**

| Species (annuals) | Average seed (no./m²) | Species (annuals) | Average seed (no./m²) |
|---|---|---|---|
| Phalaris minor Retz | 1636 | Gypsophila pilosa Huds. | 126 |
| Eremopyrum bonaepartis (Sprengel) Nevski | 1557 | Bryonia cretica L. | 126 |
| Catapodium rigidum (L.) C.E. Hubb. | 1211 | Capsella bursa-pastoris (L.) Medik | 79 |
| Bromus lanceolatus Roth | 1148 | Lappula spinocarpos (Forssk.) Asch. | 47 |
| Cardaria draba (L.) Desv. | 1007 | Ankyropetalum gypsophi-loides Fenzel | 31 |
| Poa bulbosa L. | 20587 | weed bulb | 1227 |
| Gagea spp. | 11984 | Allium desertorum Forssk | 849 |
| *Anabasis syriaca Iljin* | 8005 | Bellevalia spp. | 912 |
| *Hammada eigii Iljin* | 4105 | Achillea spp. | 991 |
| Allium erdelii Zucc. | 2501 | Erodium hirtum Willd | 582 |
| Koeleria cristata (L.) Pers. | 1132 | Atriplex halimus L. | 472 |
| Achillea fragrantissima (For-skal) Schultv Bip | 2092 | Leopoldia longipes (Boiss) Losinsk. | 315 |

**Table 5.9. Summary of the effect of different intervention on the soil seed bank.**

| Intervention | Species of maximum seed number | Maximum seed (no./m²) | SR |
|---|---|---|---|
| T[1]: CRVIC | Herniaria hirsuta L. | 77 650 | 44 |
| T[2]: CRVIW | Herniaria hirsuta L. | 187 343 | 67 |
| *T[3]: CRVCC* | Herniaria hirsuta L. | 62 877 | 46 |
| T[4]: CRVCW | Herniaria hirsuta L. | 134 988 | 69 |
| *T[5]: CRTPC* | Herniaria hirsuta L. | 54 354 | 50 |
| T[6]: CRTPW | Herniaria hirsuta L. | 142 354 | 63 |
| T[7]: Bp | Herniaria hirsuta L. | 42 876 | 41 |
| T[8]: CIG | Poa bulbosa L. | 7640 | 47 |
| T9: C – outside the intervention | Gymnarrhena micrantha Desf. | 932 | 26 |

**Table 5.10. Average seed number (no./m²) of annual and perennial plant species in the soil seed bank during June 2007.**

| Slope | Date | WH Intervention | Mean of plant no./m² |
|---|---|---|---|
| < 5% | December 2006 | T1: CRVIC | 61 klmno* |
| | | T2: CRVIW | 87 ijklm |
| | | T3: CRVCC | 80 ijklmn |
| | | T4: CRVCW | 148 efgh |
| | | T5: CRTPC | 33 no |
| | | T6: CRTPW | 109 ghijkl |
| | | T7: Bp | 32 no |
| | | T8: CIG | 30 no |
| | April 2007 | T1: CRVIC | 150 defg |
| | | T2: CRVIW | 231 b |
| | | T3: CRVCC | 71 jklmno |
| | | T4: CRVCW | 202 bcd |
| | | T5: CRTPC | 87 ijklm |
| | | T6: CRTPW | 162 cdef |
| | | T7: Bp | 60 klmno |
| | | T8: CIG | 68 jklmno |

## 5.4 Effect of microcatchments on the native vegetation

### 5.4.1 Materials and methods

For three consecutive periods (December 2006, April 2007, and April 2008) the flora in the experimental site was surveyed, to determine the effect of different WH techniques on the native vegetation. The experiment was a randomized complete block design using repeated measures for analysis, with three replicates.

The treatments in each slope were the same as used in assessment of the soil seed bank without the ninth treatment (i.e. the control outside the intervention area, but protected from grazing). The survey was carried out using the Belt Transect Method (Schmutz et al. 1982). One transect was laid down per land slope per sub-treatment. Five quadrats were placed along each transect at 10-m intervals. A total of 48 transects and 240 quadrats were surveyed for the experimental site.

### 5.4.2 Results and discussion

**Total plant species number**

An ANOVA was performed for the effect of the two slopes, the eight different interventions, and the three sampling dates: December 2006, April 2007, and April 2008 (Annex 1.12).

The three-way interaction effect of slopes, sampling dates, and interventions are shown in (Table 5.10). The CRVI intervention resulted in the highest plant number within the ridges, followed by the CRVC, and then traditional contour ridge interventions. The highest plant number was recorded in April 2007 with 1108 and 1031 plants/m² in the moderate and gentle slopes, respectively; followed by December 2006 with 774 plants/$m^2$ in the moder-

ate slope; then April 2008 with 765 and 721 plants/$m^2$ in the moderate and gentle

slopes, respectively; and the lowest value was 580 plants/$m^2$ in December 2006 in the gentle slope. This may be due to the higher amount of rainfall in April 2007 (111.2 mm) than in April 2008 (84.2 mm). Native vegetation measurement (vegetation cover, plant number, plant height, and biodiversity parameters such as SDI and SR) were highest under Vallerani contour ridges within contours intervention.

This is likely due to the Vallerani machine producing contours that are deeper and so collecting more moisture than other treatments (Suleman et al., 1995). Moisture availability is the major reason behind the higher vegetation cover, taller plants, and higher biodiversity values. In addition, the presence of shrubs can improve the natural vegetation.

The Vallerani contour ridges intervention produced the highest plant number (58–66%) of the total plants recorded in the area, whereas the traditional plow intervention produced only 11–21% of the plants.

Vallerani contour ridges within the ridges intervention produced higher plant number/$m^2$ (42–52%) compared to the Vallerani catchment area (23–31%). This is consistent with results of Rice (2004) showing that a desert water-harvester could concentrate and collect water from precipitation. ACSAD (2003) reported that microcatchment WH results in improved vegetative cover and fodder shrub plantation, and leads to restoration of the rangelands and increases runoff collection in semi-arid and arid regions.

Contours preserve more moisture, and provide a suitable habitat for as shrubs planted in the contours and other plants to grow (Tielbörger and Kadmon, 1997; Holzapfel and Mahall, 1999; Facelli and Temby, 2002).

Between the contour ridges the Gramineae family was more represented, possibly since the rapid growth of annual species gave them more time to complete their life cycle, in addition to producing more seeds and so more grass growth if moisture was available. The intermittent structure provides more moisture than the continuous or the traditional plowing.

Relative dominance of grasses was higher in the intermittent interventions, possibly because more water was preserved by such structures. For the other treatments, including the traditional plowing, the relative dominances were very close to each other, as a result of the high diversity of the area (i.e. the high number of plant species that characterize the drylands).

The Vallerani intermittent contour ridges recorded higher plant numbers/$m^2$ (15–29%) compared with Vallerani continuous contour ridges within contours (20–26%), since the deeper contours formed by the Vallerani machine when implementing the intermittent structure. This result shows the higher effect of Vallerani machine over the traditional plowing. Vallerani intermittent WH, within contours (T2: CRVIW) had higher seed numbers/$m^2$ compared to the Vallerani continuous, within contours, confirming the positive effect of the intermittent contour structure.

The barley intervention had the lowest plants/$m^2$ (4–6%) compared with the other interventions, and with no significant difference to the control treatment (5–6.6%). The highest total plant number (284 plants/$m^2$) was recorded within the ridges of the Vallerani intermittent contour ridges treatment, in samples collected in April 2007 in the moderate slope (8–12%). The lowest total plant number was for the barley plantation (27 plants/$m^2$) in samples collected in the gentle slope during April 2008.

**Table 5.10. (Continued).**

| Slope | Date | WH Intervention | Mean of plant no./$m^2$ |
|---|---|---|---|
| < 5% | April 2008 | $T^1$: CRVIC | 30 no |
| | | $T^2$: CRVIW | 210 bc |
| | | $T^3$: CRVCC | 59 klmno |
| | | $T^4$: CRVCW | 162 cdef |
| | | $T^5$: CRTPC | 114 fghij |
| | | $T^6$: CRTPW | 82 ijklmn |
| | | $T^7$: Bp | 27 o |
| | | $T^8$: CIG | 37 mno |
| 8–12% | December 2006 | $T^1$: CRVIC | 60 klmno |
| | | December 2006 | 184 bcde |
| | | $T^3$: CRVCC | 97 hijkl |
| | | $T^4$: CRVCW | 163 cdef |
| | | $T^5$: CRTPC | 35 mno |
| | | $T^6$: CRTPW | 161 cdef |
| | | $T^7$: Bp | 42 mno |
| | | $T^8$: CIG | 32 no |
| | April 2007 | T1: CRVIC | 130 fghi |
| | | T2: CRVIW | 284 a |
| | | T3: CRVCC | 60 lmno |
| | | T4: CRVCW | 228 b |
| | | T5: CRTPC | 62 jklmno |
| | | T6: CRTPW | 218 b |
| | | T7: Bp | 60 klmno |
| | | T8: CIG | 66 jklmno |
| | April 2008 | T1: CRVIC | 60 klmno |
| | | T2: CRVIW | 212 bc |
| | | T3: CRVCC | 108 ghijk |
| | | T4: CRVCW | 164 cdef |
| | | T5: CRTPC | 67 jklmno |
| | | T6: CRTPW | 85 ijklm |
| | | T7: Bp | 32 no |
| | | T8: CIG | 37 mno |

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

**Plant height**

Slopes, interventions, sampling dates, and their interaction showed significant ($P < 0.05$) effects on plant height (Annex 13). In April 2008, the highest mean plant height (8 cm) was on the moderate slope. In December 2006, the lowest plant height (3 cm) was on the moderate slope. In April 2007, the greatest average plant height (16 cm) was recorded for plants with traditional plowing within contour ridges on the moderate slope; followed by 15 cm for plants at the Vallerani contour ridges.

The lowest plant heights were under the Vallerani catchment intervention (maximum of 7 cm). The barley plantation had greater plant heights than the control treatment (6 and 5 cm, respectively). For samples collected in April 2008 in the moderate slope, the Vallerani intermittent contour ridges on the ridges intervention had plant heights of 13 cm, as did Vallerani continuous contour ridges.

The lowest plant heights were for plants in December 2006 (Table 5.11), and in general plants under barley and the control treatments were shorter plants with few exceptions. Most plant heights for the other treatments did not differ significantly from each other.

**Species richness and species evenness of the experiment site**

SR and species evenness were measured using data collected in December 2006, April 2007, and April 2008 (Annexes 1.14–1.16) to determine where to measure the SDI and EH. The highest values (SR = 57 species) were in April 2007, while April 2008 had SR = 46, and December 2006 had SR= 47.

Therefore, depending on SR results, diversity parameters of the effect of different slopes and interventions were calculated for April 2007 data, in which was also recorded the highest species evenness.

High SDI was recorded for plants within the ridges in the Vallerani intermittent contour ridges intervention (SDI = 3.21) (Table 5.12), with high species evenness within the site (EH = 0.81) as well as high SR (52 species) in the gentle slope. For the moderate slope, the highest diversity values (SDI = 2.89, EH = 0.73, and SR = 52) were for species within the ridges in the Vallerani intermittent contour ridges intervention.

Plant species within the ridges of the Vallerani continuous contour ridge intervention had high average diversity with SDI = 2.6, EH = 0.74, and SR = 36; and SDI = 2.5, EH = 0.68, and SR = 40; in the gentle and moderate slopes, respectively. This compared with the corresponding catchment area values of SDI = 1.7, EH = 0.59, and SR = 17; and SDI = 1.89, EH = 0.62, and SR = 22.

The average SDI in the Vallerani contour ridges was about 15 and 9% higher in the gentle and moderate slopes, respectively, compared with the traditional plowing; the corresponding increments in EH were 11 and 4% for gentle and moderate slopes compared with traditional plowing. SR was about 19 and 2% higher for Vallerani contour ridges in the gentle and moderate slopes, respectively, compared with traditional plowing.

The control, with no intervention and no grazing, had higher SDI (16%) and EH (13.6%) and SR (8.7%) compared with barley plantation intervention on the gentle slope. The reverse applied in the moderate slope where the barley had the higher SDI (7.4%), EH (4.2%), and SR (12%).

## 5.5 Regenerating native vegetation cover using WH techniques

### 5.5.1 Introduction

This component concentrated on the possibility of collecting plant seeds from the Mharib area and cultivating them under Mharib conditions. Two strategies for regen-

**Table 5.11. Effect of slope, sampling date, and WH interventions on mean height of native plants (cm).**

| Slope | Date | WH intervention | Mean plant height (cm) |
|---|---|---|---|
| < 5% | December 2006 | $T^1$: CRVIC | 2 lmno |
| | | $T^2$: CRVIW | 3 ghijklmnp |
| | | $T^3$: CRVCC | 3 jop |
| | | $T^4$: CRVCW | 7 nefghijklmn |
| | | $T^5$: CRTPC | 4 flmnp |
| | | $T^6$: CRTPW | 3 hop |
| | | $T^7$: Bp | 3 fghijklmn |
| | | $T^8$: CIG | 2 lmno |
| | April 2007 | $T^1$: CRVIC | 5 efghijklmn |
| | | $T^2$: CRVIW | 8 bef |
| | | $T^3$: CRVCC | 7 efghiklmn |
| | | $T^4$: CRVCW | 12 abc |
| | | $T^5$: CRTPC | 8 ceghijk |
| | | $T^6$: CRTPW | 7 efgijklmn |
| | | $T^7$: Bp | 5 efghijklmn |
| | | $T^8$: CIG | 4 fghijklmn |
| | April 2008 | $T^1$: CRVIC | 4 efghijklmn |
| | | $T^2$: CRVIW | 12 acd |
| | | $T^3$: CRVCC | 5 efghijklmn |
| | | $T^4$: CRVCW | 6 efghijklmn |
| | | $T^5$: CRTPC | 4 flmnp |
| | | $T^6$: CRTPW | 6 efghijklmn |
| | | $T^7$: Bp | 2 lmno |
| | | $T^8$: CIG | 3 ijklmnp |
| 8–12% | December 2006 | $T^1$: CRVIC | 2 npq |
| | | $T^2$: CRVIW | 6 efghijklmn |
| | | $T^3$: CRVCC | 3 mpq |
| | | $T^4$: CRVCW | 9 ce |
| | | $T^5$: CRTPC | 3 kop |
| | | $T^6$: CRTPW | 7 efghijklmn |
| | | $T^7$: Bp | 4 fghijklmn |
| | | $T^8$: CIG | 4 fghijklmn |

**Table 5.11. (Continued).**

| Slope | Date | WH intervention | Mean plant height (cm) |
|---|---|---|---|
| 8–12% | April 2008 | T1: CRVIC | 7 efghijklm |
| | | T2: CRVIW | 13 abc |
| | | T3: CRVCC | 7 efghijkln |
| | | T4: CRVCW | 15 a |
| | | T5: CRTPC | 7 efghijlmn |
| | | T6: CRTPW | 16 a |
| | | T7: Bp | 6 efghijkmno |
| | | T8: CIG | 5 efghijklmn |
| | December 2006 | T1: CRVIC | 8 bcdefgh |
| | | T2: CRVIW | 13 abc |
| | | T3: CRVCC | 7 efghijkln |
| | | T4: CRVCW | 13 ab |
| | | T5: CRTPC | 6 efghijlmn |
| | | T6: CRTPW | 6 efghijklmn |
| | | T7: Bp | 3 lpq |
| | | T8: CIG | 4 fghijklmn |

Note: * Values followed by the same letter are not significantly different at P < 0.05.

**Table 5.12. Shannon–Wiener Diversity Index (SDI), Shannon's equitability (EH), and species richness (SR) of the different interventions in the two slopes recorded for April 2007.**

| Date | WH intervention | SDI | $E_H$ | SR |
|---|---|---|---|---|
| April 2007 | T1: CRVIC | 1.70 | 0.60 | 17 |
| | T2: CRVIW | 3.21 | 0.81 | 52 |
| | T3: CRVCC | 1.83 | 0.64 | 17 |
| | T4: CRVCW | 2.36 | 0.71 | 28 |
| | T5: CRTPC | 1.53 | 0.53 | 18 |
| | T6: CRTPW | 2.33 | 0.71 | 27 |
| | T7: Bp | 1.73 | 0.57 | 21 |
| | T8: CIG | 2.06 | 0.66 | 23 |
| April 2008 | T1: CRVIC | 2.25 | 0.68 | 28 |
| | T2: CRVIW | 2.89 | 0.73 | 52 |
| | T3: CRVCC | 1.59 | 0.55 | 18 |
| | T4: CRVCW | 2.37 | 0.67 | 34 |
| | T5: CRTPC | 1.83 | 0.62 | 19 |
| | T6: CRTPW | 2.31 | 0.65 | 34 |
| | T7: Bp | 2.31 | 0.72 | 25 |
| | T8: CIG | 2.14 | 0.69 | 22 |

eration (cultivation) of the native plants were applied using different WH techniques:

1. Direct seeding, in which collected seeds were directly broadcast in the experimental site in all treatments.
2. Transplanting, in which seeds were first germinated in a greenhouse, and seedlings transplanted to the experimental site and planted in all treatments.

### 5.5.2 Materials and methods

The two regeneration methods were tested in Mharib location . The experiment was analyzed using a split-plot arrangement, with land slope (S1: < 5% and S2: 8–12%) as the main effect, the sub-treatment [$T_1$: WH with CRVI, within catchment area (CRVIC); $T_2$: WH with CRVI, within the ridges (CRVIW); $T_3$: WH with CRVC, within catchment area (CRVCC); $T_4$: WH with CRVC, within the ridges (CRVCW); $T_5$: WH with traditional contour ridges (CRTP), within catchment area (CRTPC); $T_6$: WH with CRTP, within ridges (CRTPW); $T_7$: barley plantation (BP); and $T_8$: control, with no intervention and no grazing (CIG)] as the sub-main treatments and the two regeneration methods (direct seeding and transplanting) as the sub-sub-main treatments.

#### Direct seeding method

Two experiments were implemented to test the regeneration ability of the collected plant species by direct seeding.

***The first experiment was*** begun on 26 December 2006 with 53 native plant species collected and obtained from Al Muwaqar station and from private collections in Mharib location during 2006.

**Experiment layout** Small rectangular plots (area 600 $cm^2$) with 10 cm between plots from all sides were marked on the ground in each sub-treatment. Each plot was marked by labeling a piece of wood, 50-cm long and 5-cm wide and stacked beside the field where the seeds were planted for each plant species. Of each plant species, 20 seeds were planted randomly in the plots. In each plot, one species' seeds were sown, and the soil surface was scratched to form a thin soil layer to cover the planted seeds. A total of 53 small plots were prepared in each sub-treatment per slope for the 53 native plant species and replicated three times.

Data was collected every two weeks on germination date, germination percentage, and seedling height.

***The second experiment*** was carried out for seeds of native plant species collected during June 2006 to July 2007 from the Mharib area. Seeds were cleaned and stored at 4°C, later to be directly seeded in the area. In this experiment only 10 plant species were used according to different characteristics of these species:

- *Koelpinia linearis* Pall. – a medicinal plant (Medicinal and Herbal Project 2008) that has good growth and seed production in the Mharib region.
- *Poa bulbosa* – a perennial grass adapted to the area, and has been recorded at high percentages in the survey.
- *Schismus barbatus* (L.) Thell. – a grass species highly adapted to the area and recorded in high percentages in the survey. Despite being an invasive species, it is good forage.
- *Hordeum glaucum* Steud. – another adapted grass species with high feed value.
- *Bromus lanceolatus* Roth. – a grass species showing good growth in the first experiment.
- *Astragalus cruciatus* Link. – a medicinal plant (Medicinal and Herbal Project 2008), and adapted weed species to the area, which produces a large number of seeds.
- *Hirschfeldia incana* (L.) Lagr.-Foss. – a weed species adapted to the area, which produces good vegetation cover.
- *Androsace maxima* L. – a large number of seeds is produced by this species.
- *Roemeria hybrida* (L.) DC. – a medicinal plant (Medicinal and Herbal Project 2008) and annual herb, with good veg-

etative growth and attractive flowers. *Gagea reticulata* (Pall.) Schult. & Schult.f. – a bulbous plant; however, we tried to grow its seeds. It has unique flower colors.

**Experiment layout** Ten shallow furrows (1.5 m long and 0.25 m wide) were made across the land slope in each sub-treatment, instead of the rectangular plots used in the first experiment, as they conserve more water. On 28 January 2008, due to delays in rain, seeds of the 10 plant species were directly sown into the sub-treatments. A total of 50 seeds of each plant species were sown per furrow. Seeds were covered with a fine soil layer to protect them from wind or ant damage. Fortunately, a snowfall occurred 2 d after planting.

Data were collected on emergence rate and seedling growth, number of emerged seeds, emergence percentage, seedling length, and number of harvested seeds.

**Transplanting**

Two experiments were carried out to study the possibility of seeds collected from plants from the Mharib area grown by the transplanting method and using different WH techniques.

***The first experiment*** commenced on 16 January 2007. Seeds of 48 native plant species from Al Muwaqar Station and private collections were germinated in a greenhouse at NCARE. Seeds were monitored for emergence date and percentages, and seedling length during their life-cycle in the greenhouse. Only 21 species of 48 germinated in the greenhouse, and only 10 native species were successfully transferred to the experimental site on 18 February 2007.

**Experiment layout** Transferred plants were planted near the direct-seeded plants in the sub-treatments, following the same plant species code as for the direct seeding. The plants were monitored for growth, seedling height, and the final growth stage reached.

***The second experiment*** commenced on 12 November 2007 for some native species collected from the Mharib site on June and October 2007 in the lath house (house made of lath) in Al Majidiyya village. Seeds of 17 native plant species were planted in plastic bags that contained soil from the site mixed with clay soils to increase water holding capacity.

Three seeds were planted per bag, with 48 bags per species, giving 144 seeds per species and 816 plastic bags for the whole experiment. The bags were watered and kept in the lath house at Al Majidiyya  for germination. Emergence dates, number of emerged seeds, and seedling height when transferred to the field were recorded. Only four species produced sufficient numbers of seedlings, and these were transplanted into the experiment site: *Hordeum glaucum* Steud., *Bromus lanceolatus* Roth, *Astragalus corragatus Bertol.,* and *Schismus barbatus* (L.) Thell. Plants were transferred on 13 March 2008 by planting one plant from each of the four species in each sub-treatment. Transplanted seedlings were irrigated at transplanting time. The plants were monitored during their life-cycle: flowering and fruiting dates, and seedling height were recorded. Seeds produced by each species were harvested and counted.

**Data analysis** Data was analyzed using the SAS version 9 applying a split-plot arrangement (SAS, 2002). The effect of slope, WH intervention, and rehabilitation method on seedling height, emergence percentage, survival rate, and seed production were measured.

### 5.5.3 Results and discussion

**Response of plant species to direct seeding method**

Seeds of 53 plant species were directly sown in the study area on 26 December 2006. The first emergences were recorded on 3 April 2007 for 17 species. This delay in emergence can be related to low rainfall during December–April, as reported by (Bowers 1987) and (Bainbridge 2003). The delay in emergence can also be related to some soil characteristics, such as formation of surface crust that can prevent seedling emergence, particularly those with small seeds.

Some species such as Melilotus indicus (L.) All., Hordeum glaucum Steud., Malva praviflora L., Vicia peregrina L., Androsace maxima L., Alyssum damascenum Boiss. & Gaill, Astragalus corragatus Bertol, and Medicago turbinate (L.) survived until the end of May (25 May 2007 – the final survival record). However, A. damascenum formed immature seeds (very small in size and very thin) and the other species produced no seed. This could be explained by high temperature observed late in spring. In fact, Bainbridge (2003)found that high surface temperature results in the death of plants and hence declining of the vegetation cover. Seed viability could also affect the results. The seeds for the first experiment were collected from Al Muwaqar station and private collections where storage condition may vary and so result in decreased seed viability and vigor. This in turn could affect seed germination and survival rate and eventually lead to seed death.

Maximum emergence recorded on 3 April 2007 was ≤ 75% (*Avena sterilis* L.) with the lowest for *Anthemis* sp. (15%). Seedling lengths increased very slowly until plants died at the end of May 2007. The maximum seedling length (8.6 cm) was for *Ho. glaucum* on 29 April 2007.

For the experiment conducted during the 2007/08 season, the maximum emergence on 28 January 2008 was 14% for *Koelpinia linearis Pall., P. bulbosa,* and *Astragalus cruciatus* Link. The minimum emergence percentage was 6% for G*agea chlorantha* (Bieb) Schult. Fil. All sown species showed good survival percentages, except *G. chlorantha,* in which growth terminated after 16 March 2008, and may be due to the fact that *G. chlorantha* is a perennial bulb and it is difficult to grow healthy bulbous plants from seeds. The *G. chlorantha* seeds germinated (although a very low proportion), but did not continue growing. This agrees with (Bowers 1987) in that each species responded individually to the transplanting process. It is important to note that the greatest seedling length was 18 cm for *P. sinaica,* a grass species, while the lowest was 3 cm for *Astragalus cruciatus* Link. The better results obtained durin this season, as compared to the ones of 2006/07, may be due to the planting being in January 2008, after 48.8 mm of opening rain in early January 2008. This provided sufficient moisture for seeds to germinate and grow early as explained by (Cox et al. 1982), who stated that direct seeding would succeed if there were sufficient rainfall. Most of the emerged seedlings survived and reached maturity (i.e. seed production). The growth period from January until the end of April was characterized by low–medium temperatures during March and April (14.3 and 17.8°C, respectively) and insufficient rain to support plant growth (0.4 and 0.0 mm, respectively).

The maximum survival percentage on 8 April 2007 was for K. *linearis* (44%), even though it had short stems which did not exceed 6 cm and this affected certainly the total production including grains. However, it was able to produce 43 seeds/m$^2$. The highest seed production was for *P. sinaica* (137 seeds/m$^2$), possibly due to the high adaptation of this species to the area. The lowest seed production was for the *Androsace maxima* L. (1 seed/m$^2$), possibly since this species did not grow > 5 cm in length, and the seeds were formed inside a capsule at the top of the plant. When the plant matured, the capsule opened and the seeds were shed due to any slight motion, by animal, wind, or even when harvested. The seeds were very small in size and difficult to collect from the ground after they had been shed.

**Effect of WH intervention on seedling emergence and survival rate for the planted species using direct seeding**

The ANOVA (Annex 1.15) showed a significant effect of the three studied factors on seed emergence, seedling length, and survival rate of planted species. The interaction between these factors was only significant ($P < 0.05$) for the first survival rate, third seedling length, and fourth survival rate.

The effects of the two slopes, WH interventions, and two experiment dates on emergence percentages and survival rates are shown in (Table 5.13). There were significant differences among the different interventions. There was a highly significant ($P < 0.01$) effect of the within contour ridges over the other interventions on the different parameters recorded in the two slopes and the two experiment years.

For example, for within contour ridges intervention there were higher emergence percentages (65–71%) compared with the contour ridges catchment area. The Vallerani contour ridges intervention recorded higher emergence percentages (41 and 23%) in gentle and moderate slopes, respectively, compared to traditional plowing in 2006/07; while the corresponding increments were 17 and 1% in in 2007/08.

The intervention contours (either Vallerani or traditional plowing) had emergence percentages of 4–8-fold that of barley plantations or control (no intervention, no grazing).

The average survival rate was 30% higher in the moderate compared to the gentle slope. The within contour ridges intervention had higher (82%) or equal (78%) survival rates in the gentle and moderate slopes, respectively, compared to the catchment area in the gentle slope (78%). The Vallerani intervention survival rate was higher (74 and 43%) in the gentle and moderate slopes, respectively, compared with traditional plowing.

The effect of the two slopes, different interventions, and the two experiment dates on mean number of harvested seed is shown in (Table 5.14). Harvested seed was significantly higher ($P < 0.05$) for plants in Vallerani continuous contour ridges in the gentle slope than in the moderate slope with Vallerani intermittent contour ridges. Plants within contour ridges produced 8% higher seed weight than those in the catchment area in gentle slope while within contour ridges and moderate slope they produced 79% higher seed weight than those in the catchment area. Plants in the Vallerani contour ridges produced higher weights of seeds (g/m$^2$) by 53% and 18% in the gentle and moderate slopes, respectively, compared with plants in traditionally plowed contours.

There were no significant differences in weight of seeds produced by plants in the Vallerani intermittent contour ridges and those in Vallerani continuous contour ridges (11% in gentle slope and 27% in moderate slope). The barley plantation treatment had no significant effect on the seed weight produced by plants compared with plants in the control (no intervention, no grazing.

**Behavior of the plant species in response to transplanting method**

Ten native plant species were transplanted into the site on 18 February 2007. The plants were well established in the greenhouse and were transferred to the field after 3.6 mm of rain. The temperature at the time of transplanting was moderate (9°C). The highest seedling length at the time of planting was 14.5 cm for *B. lanceolatus* and *Ho. glaucum,* while the shortest was 3.5 cm for Phalaris minor Retz. The first parameter (survival rate) was measured on 4 March 2007 and at this time the maximum survival percentage was 100% for all species, except for Ho. glaucum (82%), *Medicago turbinate* (L.) All. (86%), *Onobrychis crista-galli* (L.) Lam (91%), and *Vicia peregrina* L. (86%). The average survival

**Table 5.13. Effect of slopes, WH interventions, and planting date on emergence percentages and survival rate using direct seeding.**

| Slope | Date | WH intervention | Emergence (%) | Survival rate | | |
|---|---|---|---|---|---|---|
| | | | | 1st | 2nd | 3rd |
| < 5% | 2006/07 | T1: CRVIC | 5.97 ef | 0.78 ghi | 0.0014 f | 0.0003 f |
| | | T2: CRVIW | 21.27 a | 9.61 a | 1.86 cd | 0.69 def |
| | | T3: CRVCC | 7.15 e | 1.29 ghi | 0.0003 f | 0.0001 f |
| | | T4: CRVCW | 21.27 a | 6.67 cd | 0.69 ef | 0.10 f |
| | | T5: CRTPC | 5.29 fgi | 1.37 fghi | 0.10 f | 0 f |
| | | T6: CRTPW | 11.18 d | 2.84 ef | 0.10 f | 0 f |
| | | T7: Bp | 3.53 hk | 0.78 ghi | 0 f | 0 f |
| | | T8: CIG | 1.96 jlm | 0.49 hi | 0 f | 0 f |
| | 2007/08 | T1: CRVIC | 1.63 jklm | 2.27 efgh | 3.07c | 3.07 c |
| | | T2: CRVIW | 5.3 efgh | 10.2 a | 12.8a | 12.93 a |
| | | T3: CRVCC | 1.67 jklm | 2.13 efgh | 2.13cd | 2.13 c |
| | | T4: CRVCW | 3.13 hijlm | 9.4 ab | 11.33ab | 11.33 ab |
| | | T5: CRTPC | 0.77 m | 1.93 efghi | 2.27cd | 2.27 c |
| | | T6: CRTPW | 4.10 fghj | 9.27 ab | 9.87b | 9.87 b |
| | | T7: Bp | 1.13 lm | 1.67 efghi | 1.93cde | 1.93 cd |
| | | T8: CIG | 0.9 lm | 1.3 fghi | 1.73cde | 1.73 cde |
| 8–12% | 2006/07 | T1: CRVIC | 5.65 fg | 2.27 efgh | 0.0003 f | 0.0001 f |
| | | T2: CRVIW | 18.33 b | 10.2 a | 1.28 de | 0.59 ef |
| | | T3: CRVCC | 6.08 ef | 2.13 efgh | 0.10 f | 0.001 f |
| | | T4: CRVCW | 18.24 b | 9.4 ab | 0.69 ef | 0.10 f |
| | | T5: CRTPC | 5.78 efg | 1.93 efghi | f | 0 f |
| | | T6: CRTPW | 12.75 c | 9.27 ab | 0.10 f | 0.10 f |
| | | T7: Bp | 3.73 hk | 1.67 efghi | 0f | 0 f |
| | | T8: CIG | 0.98 m | 1.3 fghi | 0f | 0f |
| | 2007/08 | T1: CRVIC | 1.23 lm | 2.17 efgh | 2.13 cd | 2.13 c |
| | | T2: CRVIW | 4.50 fgh | 9.23 ab | 10.33 b | 10.33 b |
| | | T3: CRVCC | 1.23 lm | 2.47 efg | 2.33 cd | 2.33 c |
| | | T4: CRVCW | 3.6 ghjl | 8.2 abc | 9.93 b | 9.87 b |
| | | T5: CRTPC | 1.1 lm | 2.17 efgh | 2.07 cde | 2.07 c |
| | | T6: CRTPW | 4.13 fghj | 8.87 ab | 10.0 b | 10.0 b |
| | | T7: Bp | 1.03 lm | 1.4 fghi | 1.87 cde | 1.93 cd |
| | | T8: CIG | 1.07 lm | 1.33 fghi | 1.83 cde | 1.80 cde |

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

**Table 5.14. Effect of slopes and WH interventions on harvested seed (g/m$^2$) using direct seeding in 2007/08.**

| Slope | WH intervention | Harvested seed (g/m$^2$) |
|---|---|---|
| < 5% | $T^1$: CRVIC | 5 d |
| | $T^2$: CRVIW | 27 a |
| | $T^3$: CRVCC | 55 d |
| | $T^4$: CRVCW | 24 ab |
| | $T^5$: CRTPC | 5 d |
| | $T^6$: CRTPW | 21 bc |
| | $T^7$: Bp | 3 d |
| | $T^8$: CIG | 2 d |
| 8–12% | $T^1$: CRVIC | 4 d |
| | $T^2$: CRVIW | 22 abc |
| | $T^3$: CRVCC | 5 d |
| | $T^4$: CRVCW | 18 bc |
| | $T^5$: CRTPC | 4 d |
| | $T^6$: CRTPW | 16 c |
| | $T^7$: Bp | 4 d |
| | $T^8$: CIG | 3 d |

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

percentage for *Melilotus indicus* (L.) All. was (94%), and the average mean percentage for *Silene coniflora* L was ≤ 53%. The maximum initial seedling length (13.4 cm) was for *Ho. glaucum.*

Transplanting of native species, produced from seeds collected from the same area to be restored, produced satisfactory results. Such good results agree with those of Bainbridge (2003), who found that the vegetation rehabilitation in arid lands usually required transplanting to re-establish plants; and that it should be done with seed collected from the site to be rehabilitated. The growth of *Peganum harmala* L., *Ph. minor,* and *Polygonum equisetiforme* Sm. ceased before 29 March 2007 (the final record for these species was on 17 March 2007), when their average survival rates were 13, 2, and 14%, respectively. After two weeks, B. *lanceolatus, Ho. glaucum, Medicago turbinate,* and *V. peregrina* failed to survive. The other plant species were dead when monitored on 13 April 2007. This is likely due to the high temperatures experienced after transplanting (Bowers 1987; Bainbridge 2003).

For the second experiment (2007/08), the growing seedlings were transferred to the experiment site on 13 March 2008 due to delays in rain. Four of the 17 native species were planted in the experiment site. Seedling length and survival rates were recorded at two-week intervals, until harvesting of seeds on 20 April 2008. All four species had 100% survival on 13 March 2008. However, by the end of the season (10 April 2008), the survival rate had declined to 28, 22, 16, and 8% for *B. lanceolatus, Ho. glaucum, Schismus barbatus* (*Loefl. ex L.*) Thell. and *Astragalus cruciatus* Link., respectively.

The highest seed number produced (26 seeds/m$^2$) was for *Schismus barbatus,* and the lowest (8 seeds/m$^2$) for *A. cruciatus.*

**Table 5.15. Effect of slopes, WH interventions, and planting dates on the survival rate using transplanting.**

| Slope | Date (growing season) | WH intervention | Survival rate | | |
|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd |
| <5% | 2006/07 | T1: CRVIC | 52.23 cde | 19.63 c | 5.13 c |
| | | T2: CRVIW | 41.70 def | 14.90 c | 4.47 c |
| | | T3: CRVCC | 50.80 cdef | 17.83 c | 3.00 c |
| | | T4: CRVCW | 32.53 f | 10.50 c | 1.43 c |
| | | T5: CRTPC | 45.70 cdef | 16.57 c | 6.27 c |
| | | T6: CRTPW | 46.73 cdef | 16.47 c | 6.07 c |
| | | T7: Bp | 56.13 bcde | 23.77 c | 5.47 c |
| | | T8: CIG | 48.20 cdef | 11.07 c | 1.03 c |
| | 2007/08 | T1: CRVIC | 75.00 ab | 75.00 b | 75.00 b |
| | | T2: CRVIW | 100.00 a | 100.00 a | 100.00 a |
| | | T3: CRVCC | 100.00 a | 100.00 a | 100.00 a |
| | | T4: CRVCW | 100.00 a | 100.00 a | 100.00 a |
| | | T5: CRTPC | 91. 67 a | 91.67 ab | 91.67 a |
| | | T6: CRTPW | 100.00 a | 100.00 a | 100.00 a |
| | | T7: Bp | 100.00 a | 100.00 a | 100.00 |
| | | T8: CIG | 100.00 a | 100.00 a | 100.00 a |
| 8–12% | 2006/07 | T1: CRVIC | 44.50 cdef | 14.27 c | 2.33 c |
| | | T2: CRVIW | 62.97 bc | 24.33 c | 5.50 c |
| | | T3: CRVCC | 40.73 def | 13.10 c | 2.73 c |
| | | T4: CRVCW | 39.267 ef | 15.67 c | 5.00 c |
| | | T5: CRTPC | 46.03 cdef | 19.30 c | 4.50 c |
| | | T6: CRTPW | 59.00 bcd | 19.73 c | 5.10 c |
| | | T7: Bp | 47.20 cdef | 14.27 c | 2.93 c |
| | | T8: CIG | 40.70 def | 12.23 c | 1.33 c |
| | 2007/08 | T1: CRVIC | 100.00 a | 100.00 a | 100.00 a |
| | | T2: CRVIW | 100.00 a | 100.00 a | 100.00 a |
| | | T3: CRVCC | 100.00 a | 100.00 a | 100.00 a |
| | | T4: CRVCW | 100.00 a | 100.00 a | 100.00 a |
| | | T5: CRTPC | 100.00 a | 100.00 a | 100.00 a |
| | | T6: CRTPW | 100.00 a | 100.00 a | 100.00 a |
| | | T7: Bp | 100.00 a | 100.00 a | 100.00 a |
| | | T8: CIG | 100.00 a | 100.00 a | 100.00 a |

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

**Effect of WH intervention on seedling emergence and survival rate for transplanted species**

ANOVA of the effect of slopes, transplanting dates, and the different interventions on rehabilitation using transplanting is illustrated in Annex 1.16.

There was a highly significant effect *($P < 0.001$)* of the two dates at all growth stages, except for initial seedling length (Annex 1.18).

The effect of slope was significant *($P < 0.05$)* at all growth stages, except for the initial stage and the first seedling length. The interventions had no significant effect on the transplanting method, except for the second seedling length (Annex 1.17).

The effect of the three-way interaction of slopes, interventions, and experiment dates on survival rate is shown in (Table 5.15). Plants in the 2007/08 season had taller seedlings and higher survival rates than those planted in 2006/07 at all growth stages in the two slopes. There were no significant differences between the different interventions, even though, the within contour ridges showed higher survival rate (18% in the first growing season and 12% in the second growing season) compared with the catchment area in the gentle slope. For the moderate slope, the within contour ridges recorded a higher (although non-significant) survival rate (18.9% in the first season only) compared with the catchment area. Planting the contours with shrubs improved the micro-habitats and enabled native plants to re-grow on the site, similar to previous findings (Hassan and West, 1986; Tilbörger and Kadmon, 1986; Aguiar and Sala, 1994). There was no significant difference between the survival rate of plants in Vallerani interventions at $P < 0.05$ compared with traditional plowing for the gentle slope (the real difference was small and not significant but higher for traditional plowing than the Vallerani intervention by 4 and 2% in the first and second growing seasons, respectively). This difference was also small in the second growing season (for the first growing season only, the survival rate was higher by 11% for plant species planted in traditional plow compared with that planted in the Vallerani interventions).

The survival of plants in the barley plantation treatment was 14% higher (non-significant), only in the gentle slope in the first growing season, compared with the control (no intervention, no grazing).
The effect of slopes, interventions, and experiment dates on the seed harvested is shown in (Table 5.16). Plants within contour ridges produced a significantly greater ($P < 0.05$) weight of seed than those in the catchment area (by 45 and 46% in the gentle and moderate slopes, respectively).

The weight of seeds produced from plants in the catchment area was higher than those within Vallerani interventions (by 27 and 32% in gentle and moderate slopes, respectively). Plants in the Vallerani intermittent contour ridges produced a greater weight of seeds (by 24%) than those in Vallerani continuous contour ridges in the gentle slope only (although non-significant); and there were no differences for the moderate slope.

## 5.6 Seed propagation/multiplication of potential native plant species

### 5.6.1 Materials and methods

Native plant species were tested for their seed multiplication. The seeds used were from those collected during the study period from Mharib and Al Majidiyya areas, NCARE soil seed bank, and Al Muwaqar Station (University of Jordan). On March 2007, seeds of 26 native plant species (Table 5.17) were sown into a greenhouse. Only eight species (Table 5.17) survived,

**Table 5.16. Effect of slopes, WH interventions, and planting date on harvested seed (g/m²) for the transplanting method.**

| Slope | WH intervention | Harvested seed (g/m²) |
|---|---|---|
| < 5% | T1: CRVIC | 6 bcde |
| | T2: CRVIW | 15 a |
| | T3: CRVCC | 5 bcde |
| | T4: CRVCW | 7 bcd |
| | T5: CRTPC | 5 cdef |
| | T6: CRTPW | 7 bc |
| | T7: Bp | 4 defg |
| | T8: CIG | 2 fg |
| 8–12% | T1: CRVIC | 3 efg |
| | T2: CRVIW | 8 b |
| | T3: CRVCC | 5 bcdef |
| | T4: CRVCW | 5 bcde |
| | T5: CRTPC | 2 fg |
| | T6: CRTPW | 5 cdef |
| | T7: Bp | 3 efg |
| | T8: CIG | 1 g |

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

and they were transplanted under drip irrigation to the field at Mobis Station (NCARE) on September 2007.

Plants were monitored for growth. Seeds were harvested on December 2007 (unusually high temperatures enabled the plants to produce seeds) and again on April 2008. Seeds were counted and 100-seed weights recorded.

### 5.6.2 Results and discussion

The highest harvested seed weight (38.4 g/m²) was for *Sinapis alba* L. (Table 5.18). The highest number of seeds harvested (41 064 seeds/m²) was for *Schismus barbatus* (Loefl. ex L.) Thell., followed by *Eremopyrum bonaepartis* (Sprengel) Nevski (13 783 seeds/m²).

### 5.6.3 Conclusions

Natural vegetation is diverse and variably distributed according to site differences. Annual plant species dominated the study area, and can be used as indicators of degradation in the Mharib region.
A combination of WH intervention and protection from grazing is essential to improve the natural vegetation cover.
Microcatchment WH had a significant effect on increasing the native vegetation of the study area by improving biodiversity as well as the size of the soil seed bank.
Plots with the intervention of Vallerani intermittent contour ridges were best at improving and preserving the native vegetation in terms of high SR, high total number of plants, and the size of the soil seed bank.

**Table 5.17. Plant species used their seeds for multiplication.**

| Number | Species | Number | Species |
|---|---|---|---|
| 1 | Adonis dentata Del. | 14 | Hypecoum procumbens L. |
| 2 | Adonis palaestina Boiss. | 15 | Hirschfeldia incana (L.) Lagr.-Foss. |
| 3 | Allium erdelii Zucc. | 16 | Hordeum glaucum Steud. |
| 4 | Alyssum damascenum Boiss. & Gaill. | 17 | Leopoldia longipes (Boiss.) Losnik. |
| 5 | Androsace maxima L. | 18 | Catapodium rigidum (L.) C.E.Hubb. |
| 6 | Anthemis palestina Boiss. | 19 | Malva sylvestris L. |
| 7 | Astragalus annularis Forssk. | 20 | Phalaris minor Retz. |
| 8 | Astragalus asterias Hohen | 21 | Poa sinaica Steud. |
| 9 | Eremopyrum bonaepartis (Sprengel) Nevski | 22 | Roemeria hybrida (L.) DC. |
| 10 | Erodium hirtum Willd | 23 | Schismus barbatus (L.) Thell. |
| 11 | Eruca sativa Mill. | 24 | Silene coniflora Otth. |
| 12 | Gagea reticulata (Pall.) Schult. & Schult.f. | 25 | Sinapis alba L. |
| 13 | Helianthemum ledifolium (L.) Mill. | 26 | Sisymbrium irio L. |

Note: Plant species in bold are those species that manage to survive and were transferred to Mobis Station (NCARE).

**Table 5.18. Total seed weight, 100-seed weight, and total number of seeds of eight native plant species at Mobis Station (NCARE) in 2006/07.**

| Plant Species | Total seed weight (g) | 100-seed weight (g) | Total number of seeds |
|---|---|---|---|
| Androsace maxima L | 0.9653 | 0.0400 | 2413 |
| Sinapis alba L. | 38.38 | 0.4474 | 8578 |
| Eremopyrum bonaepartis (Sprengel) Nevski | 21.7490 | 0.1578 | 13 783 |
| Hordeum glaucum Steud. | 14.8271 | 0.6101 | 2430 |
| Catapodium rigidum (L.) C.E. Hubb. | 3.1800 | 0.1075 | 2958 |
| Alyssum damascenum Boiss. & Gaill | 4.4731 | 0.3334 | 1342 |
| Poa sinaica Steud. | 3.9491 | 0.050 | 7898 |
| *Schismus barbatus* (Loefl. ex L.) Thell. | 16.7953 | 0.0409 | 41 064 |

Direct seeding was a good practice for native vegetation rehabilitation, due to low cost and effort required, but cannot guarantee germination due to rainfall variability and soil surface crust formation. However, transplanting was more promising, even with higher costs and greater effort required.

Native plants can be multiplied under controlled conditions, and the seeds produced form a valuable source for rangeland rehabilitation
.
There are some difficulties concerning the regeneration of native plant species, concerning timing and follow up.
The soil seed bank survey indicated potential for the study area if other conditions can be improved, mainly conservation of soil moisture. In addition to this, management (protection from grazing) is essential.

### 5.6.4 Recommendations

Areas where the interventions have been implemented should be protected, to enable collection of native seeds for regeneration.
More detailed studies are required to improve the regeneration methodology for herbaceous plant species in order to rehabilitate degraded rangelands.

Emphasis should be on perennial plant species for rangeland sustainability.
Seeds from this study were deposited in the seed bank at NCARE, adding to the collection of seeds from natural plants.

Conservation of this material will form a good resource for future work on multiplication and regeneration of native rangeland plant species.

The mechanized Vallerani intermittent microcatchment WH technique should be applied on a large scale (of technology transfer) in rangelands that receive 100–200 mm rainfall.

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