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Alteration of the *Rhanterium epapposum* plant community in Kuwait and restoration measures

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This paper reviews the importance of *Rhanterium epapposum* plant community in Kuwait and more generally in the region, together with reporting efforts to assess environmental impact on the *Rhanterium* community and the steps taken to establish revegetation. The authors make recommendations to reduce desertification and to restore the plant community.

Keywords: Biodiversity; Succession; Desertification; Revegetation; Deserts; Rangelands

1. Introduction

Natural vegetation is an important source of sustainable benefits to society. It provides low-cost feed opportunity for livestock grazing and sources of seed and genetic diversity, energy in the system, and organic matter to the soil. In areas vulnerable to wind erosion, such as arid lands, vegetation reduces soil erosion and captures mobile sand as well as improving percolation of water through the soil. The land use map in Kuwait shows that about 75% of the areas are used for livestock grazing [1]. Early studies by Dickson [2] distinguished three main plant communities that are heavily used for livestock grazing in Kuwait, namely, *Haloxylon salicornicum* (Moq.) Bunge ex Bioss, *Rhanterium epapposum* Oliv. and *Cyperus conglomeratus* Rottb. Kernick [3] added one more community to the list (*Zygophyllum qatarense* Hadidi).

Based on variations in the habitat characteristics (landform and soil characteristics), the floristic composition and the dominant species, Halwagy and Halwagy [4] identified four desert ecosystems in Kuwait, *viz.* sand dune ecosystem, salt marsh and saline depression ecosystem, desert plain ecosystem and desert plateau ecosystem. Each of these ecosystems is characterized by a dominant plant community and is associated with several other species. Subsequently, based on additional information gathered during the soil survey of Kuwait project, Omar *et al.* [5] suggested six ecosystems: coastal plain and lowland ecosystem;

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desert plain and lowland ecosystem; alluvial fan ecosystem; escarpment; ridge and hilly ecosystem; wadi and depression ecosystem; and burchan sand dune ecosystem.

Dickson and Macksad [6] compiled the list of plants occurring in Kuwait, which was later modified by Omar [7]. Omar identified 285 species. The more recent studies indicated an increase in the total number of species to 374 [8]. As in other arid and semiarid countries, annuals are the most dominant species (256 species), followed by herbaceous perennials (83 species), shrubs and under shrubs (34 species) and tree (one) species. The vegetation map showing the distribution of the prime species was initially developed by Halwagy and Halwagy [9] and subsequently revised by Omar *et al.* [10].

Kuwait's native vegetation is of enormous scientific value because it represents a transition between semi-desert and desert vegetation, highly vulnerable to human induced changes. It therefore serves as an effective indicator of human perturbation [5]. It also offers valuable gene pool and plant material for drought and salt-tolerance research.

2. General features of *Rhanterium epapposum* community in Kuwait

Rhanterium epapposum is the national plant of Kuwait. A C_3 shrub, it is the most abundant shrub over wide tracts of area in north and central Arabia, mainly between 25°N and 30°N [11]. As it needs regular winter rainfall to germinate and survive, it is increasingly a rare species in the farther southern part of Arabia. The *Rhanterium epapposum* plant is a roughly spherical, bushy shrub, approximately 50–100 cm tall. It has several slender highly glabrous branches arising from the base which appear highly reflective during the dry season (figure 1). The leaves are small and narrow, usually developing after the first rains, although occasionally, initial leaf development precedes rainfall. These leaves are shed toward the end of spring, and the plant remains dormant during the hot summer months.

Normally, flowering takes place in spring (April–May) when leaf development is complete, but the plant tends to flower prior to the completion of leaf development if the rainfall is

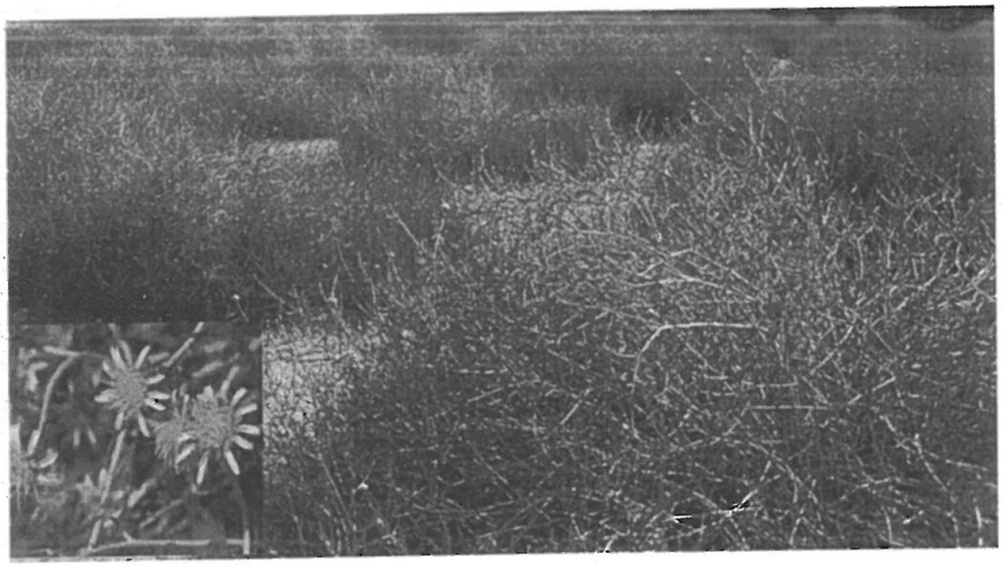

Figure 1. Pure stand of *Rhanterium epapposum* at the Sulaibiya Experimental Station in Kuwait.

sparse. The fruit, called capitulum, containing six to eight seeds are shed at the end of spring and remain dormant in the ground throughout the summer. The capitulum is the unit of dispersal, and is either blown to short distances by wind or transported to long distances by animals (sheep, goat, camels). Seeds germinate while the achenes are still located in the capitulum and usually coincide with the onset of the rainy season in the following autumn. For germination to take place, the capituli must be positioned upright with their basal part on the ground. Although several seedlings emerge from each capitulum, only a few survive due to competition. The seeds remain viable for more than four years under ambient conditions [12].

In Kuwait, the *Rhanterium epapposum* community along with other dominant communities such as the *Haloxylon salicornicum*, *Cyperus conglomeratus* and *Panicum turgidum*, Forssk. occur in the desert plain ecosystem, which extends between the west of the coastal plain and southwestern borders and into the northeastern part (figure 2a). The *Rhanaterium*

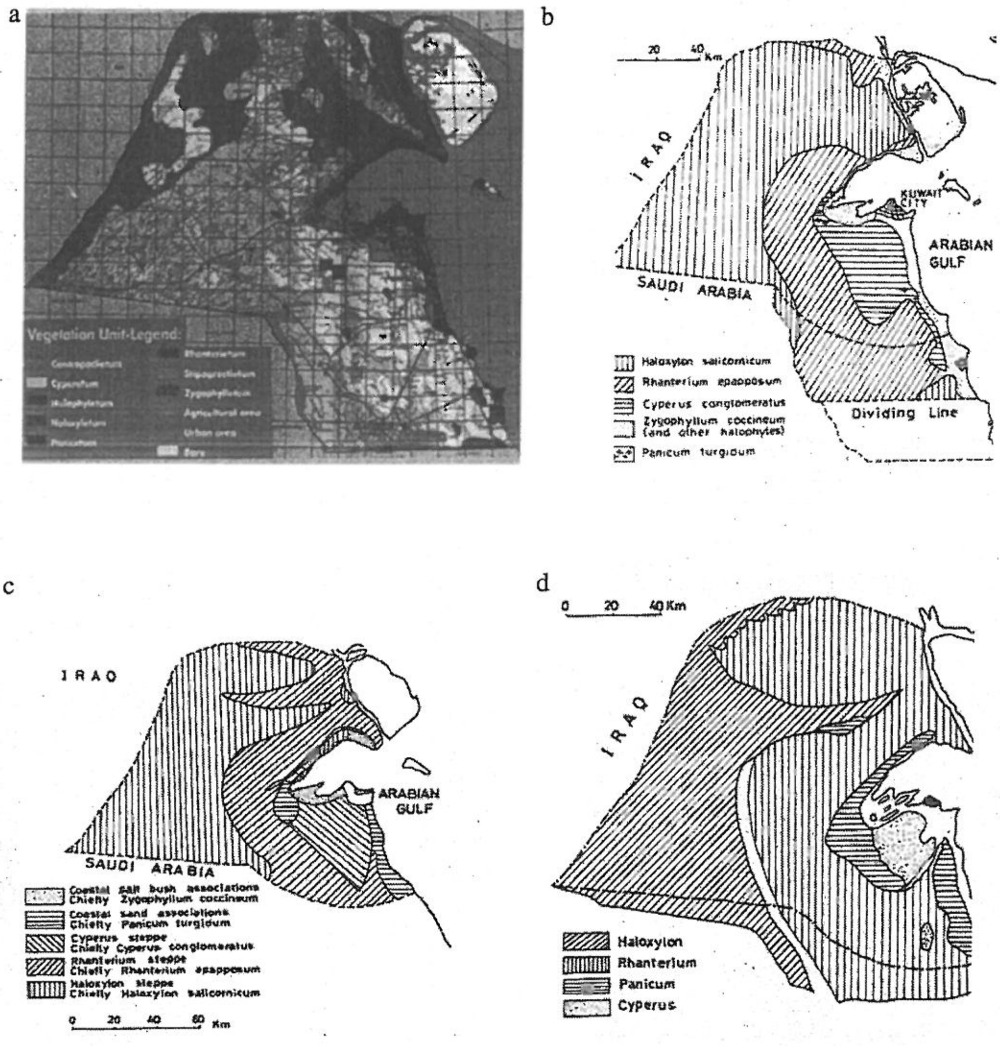

Figure 2. The vegetation maps of Kuwait. Sources: a) Omar *et al.*, 2000 [5]; b) Halwagy and Halwagy, 1974 [9]; c) Kernick, 1966 [3]; d) Dickson, 1955 [2].

community is found on calsygypsids soils in the northern and torripsamments (deep sandy soils) and petrocalcid soils in the southern part of Kuwait.

The *Rhanterium* is commonly associated with *Convolvulus oxyphyllus*, *Centropodia forsskalii* (Vahl) Cope, *Farsetia aegyptia* Turra, *Helianthemum lippii* (L.) Dum. Cours., *Moltkiopsis ciliate* (Forssk.) I. M. Johnston. and *Stipagrostis plumoae* (L.) Murno ex T. Anders [5]. It is also associated with *Gynandriris sisyrinchium* Parl. in shallow depressions, *Horwoodia dicksoniae* Turrill. and *Cornulaca aucheri* Moq. in mobile sandy areas and with *Anthemis deserti* Boiss, *Schimpera arabica* Sochst. Et Steud., *Arnebia decumbens* Ven. Coss and Karl., *Arnebia tinctoria* Forssk., *Cutandia memphitica* (Spreng.) Benth and *Plantago boissierri* Hausskn. and Bornm. in stable soils. Out of these, *Plantago boissierri* is the most widespread and abundant annual associated with *Rhanterium* [10]. This community covers 2.1% of the total area. The dominant plant species, *R. epapposum* is highly susceptible to grazing.

3. Succession of *Rhanterium epapposum* in Kuwait

Plant survival and existence are determined by conditions in the ecosystem in which they occur. The ecosystem is dynamic, and it changes in overlapping scales of time and space. Certain species dominate immediately after the occurrence of disturbances such as overgrazing, gravel quarrying, pollution, fire, etc., where the dominant species is replaced by a secondary dominating species normally associated with it. Early dominants are small in size, maturing quickly and have short life spans. Year after year, a successive series of developmental communities (series) leads to a more stable community.

Based on three decades of field observations made on two primary steppes, *H. salicornicum* and *R. epapposum*, Omar [5] suggested a succession model called Range Succession and State/Transition (RSST), developed by combining the two models: Range Succession [13,14] and State/ Transition Model [15]. As shown in figure 3, this model comprises seven states (boxes) and 16 transitions (arrows). The climax or stable perennial species occur at the upper levels of the model and hence, the range condition at this level is also good. In contrast, annual species dominate, or the ground becomes denuded at the lower level of the RSST model. Consequently, the range condition at this level is very poor. The natural (precipitation, drought, soil erosion and sand accumulation) and human-associated (e.g. logging of woody shrublets), camping, off-route vehicle use and grazing (light, moderate or heavy) factors induce changes in vegetation, and hence, shift the succession states to lower levels.

The time scale for ecosystem changes can be short (less than 24 hours to one growing season) or long (several seasons). The short cycles relate to sudden changes within the individual that occur within 24 hours (leaf formation, flowering and seed dissemination, plant morphological changes), or certain random changes occurring during the growing season. The animals (stocking rate) play a major role in determining survival and transfer of vegetation from State VI to V, whereas the precipitation, drought (wet/dry cycles), temperature extremities (too hot/frosts), sand movement, soil erosion and soil compaction determine the direction of succession from State VI to III or IV. Removal of top soil by wind, exposure of hard pan layer and absence of vegetation cover transfer the vegetation to State VII. While resting and improvement of soil physical characteristics (organic matter, soil texture and water holding capacity) shift the vegetation from State III to State I, continued heavy grazing converts the State III into State V. Any change in these conditions will influence the time taken to attain the upper State. Continuous soil erosion and changes

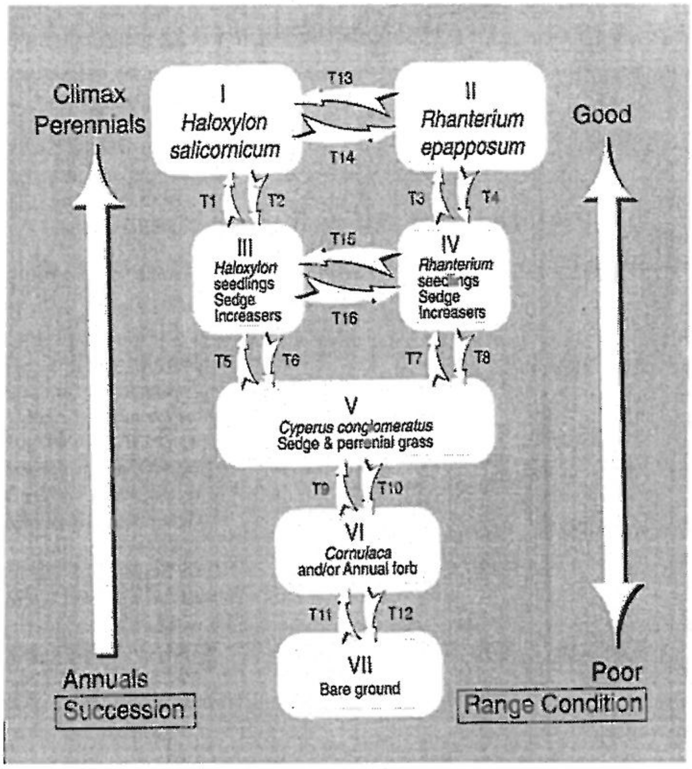

Figure 3. RSST succession model for *Rhanterium* and *Haloxylon* community types (I–VII, refer to successional stages and T1–T14 refers to transitional periods (Omar *et al.*, 2000 [5]).

in soil physical characteristics may cause vegetation to change from State I to II, and moderate grazing and logging can move the vegetation to States III and IV.

In this succession model, State I is dominated by the shrublet *H. salicornicum*, which occurs in clumps on shallow hard *gatchy* (local term for hard surface layer containing calcium carbonate, gypsum, silica or other cementing material) or consolidated soil with bare ground in open spaces. State II is dominated by *R. epapposum* which occurs in moderately deep sandy soil with bare ground possibly occupied by its roots. When conditions are stable the two community types form distinct boundaries. In areas where the upper soil is disturbed due to soil erosion or sand accumulation, one of these community types may replace the other. Halwagy and Halwagy [9] also suggested that *H. salicornicum* replaces *R. epapposum* as a result of overgrazing, logging or soil erosion. Therefore, transitions 13 (T13) or 14 (T14) could occur due to changes in soil physical characteristics, competition in mixed stands of the two communities or grazing. These two States support abundant wildlife populations.

States III and IV convert to upper or middle States. For example, State III converts to State I by overresting (T1) or to State V by logging and/or moderate to heavy grazing. State IV converts to State II by overresting (T3) or to State V by logging and/or moderate to heavy grazing (T8). The time required for the two States to convert to upper States in the model is from 7 to 10 years. Persistence of drought causes dormancy and death of perennials. It may delay the succession progress or may make the succession regress to lower states. In these two States, sedge (*C. conglomeratus*) dominates in association with *P. turgidum*.

Seedlings of *H. salicornicum* and *R. epapposum* may still be present in States III and IV, respectively, as subterranean stumps or intensively grazed twigs. Soil is moderately stable but slightly vulnerable to wind erosion. Among the common associated species in State III are S. *capensis,* and in State IV, *Stipagrostis* spp., *P. boissierri* and *C. memphitica*. The two States have diversity and palatable species. Desert animals such as lizards and jerboas are abundant at State III, while State IV can only support a few animals (such as lizards).

State V is characterized by the absence of shrublet, and is dominated by sedge and other associated perennial grasses. Seedlings of *R. epapposum* and *H. salicornicum* are absent and increasers (plants that increase with heavy grazing) such as *P. boissierri* and *A. decumbens* as well as invaders (plants that were not present in the climax state) such as *C. ausheri* become common. Under good precipitation conditions and restoration of the rangelands (T5 and T7) State V could convert to either States III or IV depending on soil type characteristic. However, if pressure from grazing and drought continue to occur (T10), the State regresses to State VI. The period required for State V to progress to upper succession states is between five and eight years which could be achieved by relaxation from grazing pressure and human-associated factors, as well as the occurrence of a good amount of precipitation (T5 and T7), particularly during spring. While State V supports mostly lizards and insects, States VI and VII are poor in wildlife populations.

States VI and VII are the lower States of RSST model. The former state is dominated by increasers, mainly *P. boissierri*, and invaders such as *C. ausher, M. ciliata, S. plumosa* may be present in certain locations. Drought, coupled with overgrazing, intensive human activities, removal of topsoil and wind erosion or burial of vegetation by mobile sand (T12) are the main causes of transferring the state of the range from State VI to State VII. State VII is mainly bare ground, and the topsoil become extremely vulnerable to wind erosion especially during summer. In State VI, animals become less selective in grazing with low productivity potential. Therefore, it is highly undesirable relative to upper states. The periods required are between five and seven years in converting from State VI to State V, and three to five years from State VII to VI. The transition could be achieved by a relaxation of the rangeland from grazing pressure with an adequate amount of precipitation (T11 and T9), or by applying rangeland improvement techniques such as seeding or revegetation. Transition 9 is to be chosen to avoid transition 12.

By identifying the succession states to which the rangelands transfer under certain conditions (e.g. climatic circumstances in conjunction with grazing), it becomes possible to define the necessary management approach. For example, if the range is in State VI that requires to be converted to State V, a reduction of stocking rate and restoration may be the appropriate management scheme. It should be noted, however, that rangelands could be most productive during State III for the *Haloxylon* steppe and State IV for the *Rhanterium* steppe, because of species-diversity and the presence of more palatable species. States I and II, however, have conservation value for wildlife and habitats. In general, the overall period required in converting a range from State VII to State I or II will be from 20 to 30 years. This period however, requires restoration, rehabilitation and above normal precipitation.

4. Detection of alterations in the *Rhanterium epapposum* community in Kuwait

Deserts are generally regarded as fragile ecosystems that are highly vulnerable to anthropogenic disruptions [5,16–20]. Overgrazing has been the primary cause of desertification in Kuwait [19]. This has led to the complete destruction of the shrub vegetation in many areas. Because sheep, goat, and camels prefer *Rhanterium*, it is heavily grazed in the rangeland. These animals graze the fresh green growth and the woody stumps of *Rhanterium* to such an extent that they are not visible above the surface. This leads to a significant reduction in the available biomass both in quality and quantities, hence, reducing the rangeland's productivity. Overgrazing due to increase in animal numbers or heavy use of a few animals in one area results in overuse, loss of vigour and ultimately disappearance of desirable plants (decreasers) and increase in less desirable species (increasers) or their replacement by invaders.

Brown [18] provides the list of species classified according to their grazing preference and the ability to spread in the range. *Rhanterium epapposum* and some of the associated species (*Astragalus annularis, Cutandia memphitica, Helianthemum lippii*) were classified as decreasers, whereas species such as *Arnebia decumbens, Brassica tournefortii, Cakile arabica and Cyperus conglomeratus, Farsetia aegyptia, Horwoodia dicksoniae, Moltkiopsis ciliate, Malcolmia grandiflora, Plantago boissierii, Picris saharae* and *Silene arabica* were increasers.

The current vegetation map of Kuwait [10] shows eight vegetation map units: Haloxyletum, Rhanterietum, Cyperetum, Stipagrostietum, Zygophylletum, Centropodietum, Panicetum and Halophyletum (figures 2a–1d). In comparison with previous studies, the current vegetation map shows alteration in the distribution of plant communities. According to Kernick [3], the *Rhanterium epapposum* community covered over 526,000 ha (40% of the total area covered by vegetation) in 1963. In 1974, the area covered by the *Rhanterium epapposum* community was considerably reduced to 30.6% (figure 2b). At present, it covers only 2.1% in the vegetated area [10]. Only 0.6% of the area has remained unchanged. This indicates that this community has considerably retreated from the rangelands of Kuwait, and that the community is more susceptible to grazing than *Cyperus conglomeratus*.

The current situation of *Rhanterium* is very critical in most areas of Kuwait. Currently, it is confined to protected areas, such as at the Sulaibiya Experimental Station (SES), military camps, military air bases and some protected oil fields [10]. A combination of overgrazing, cutting and off-road driving contributed to this decline in the area. Because it is more susceptible to grazing than *C. conglomeratus*, areas that were overgrazed became depleted of *Rhanterium* and replaced by *Cyperus* as the dominant perennial sedge. In that sense, *Cyperus* can be considered as the degradation stage of the *Rhanterium epapposum* community. This was well demonstrated at SES, which has been completely protected from grazing since 1979, whereas in overgrazed areas immediately outside the station, *Cyperus* has prevailed with *Rhanterium* almost absent. Nevertheless, *Rhanterium* can regenerate rapidly from underground stems on sandy hollows.

5. Factors responsible for degradation of *Rhanterium epapposum* community in Kuwait

Faced with a highly unpredictable environment with respect to water availability, a relatively short growth period and extreme aridity, the desert plants are under tremendous pressure and are subjected to large fluctuations over time. Prior to the Gulf War, rangeland deterioration resulted from overgrazing, off-road vehicular movements, uprooting of plants, sand encroachment, and drought. After the Gulf War, the rangeland renewable resources were subjected to additional physical (disruption of soil by placement of mines, construction of bunkers, foxholes, movement of heavy machinery) and chemical pollution caused by large numbers of devastated oil wells. Specifically, interacting environmental and human factors responsible for deterioration of rangelands in Kuwait are as follows:

- Environmental factors (extreme aridity, frequent drought and below average precipitation);
- Overgrazing by livestock;
- Off-road traffic;
- Spring camping and recreation;
- Gulf Wars and military activities during invasion and occupation;
- Gravel quarrying; and
- Development of irrigated agriculture.

Environmental factors. Seedling establishment often represents the crucial phase in the life history of a plant. In perennials like *Rhanterium epapposum*, the regeneration of new shoots from dormant parts plays an important role in the continuation as well as in the spread of the species. Factors like temperature and precipitation have a major influence on species composition, seed germination, seedling establishment and biomass production in any given year [21,22]. Precipitation is directly correlated to the total amount of vegetation (figure 4). But, biomass production in species like *Rhanterium epapposum* and *Plantago boissieri* is not significantly correlated to annual/seasonal precipitation [21].

Overgrazing. Grazing of native vegetation has historically been a mainstay of the nomadic people of Arabia. Overgrazing not only lowers productivity, but also affects species richness and relative abundance. The open graze policy in Kuwait is a primary cause for degradation of rangeland. Stocking rates in Kuwait are high (2–8 ha/AU; 1 AU = mature female camel, or 5 sheep or Ca. 6 goats). This is nearly seven times more than the land can safely carry [23]. More recent records show that stocking rates in the rangelands of Kuwait are very high. In

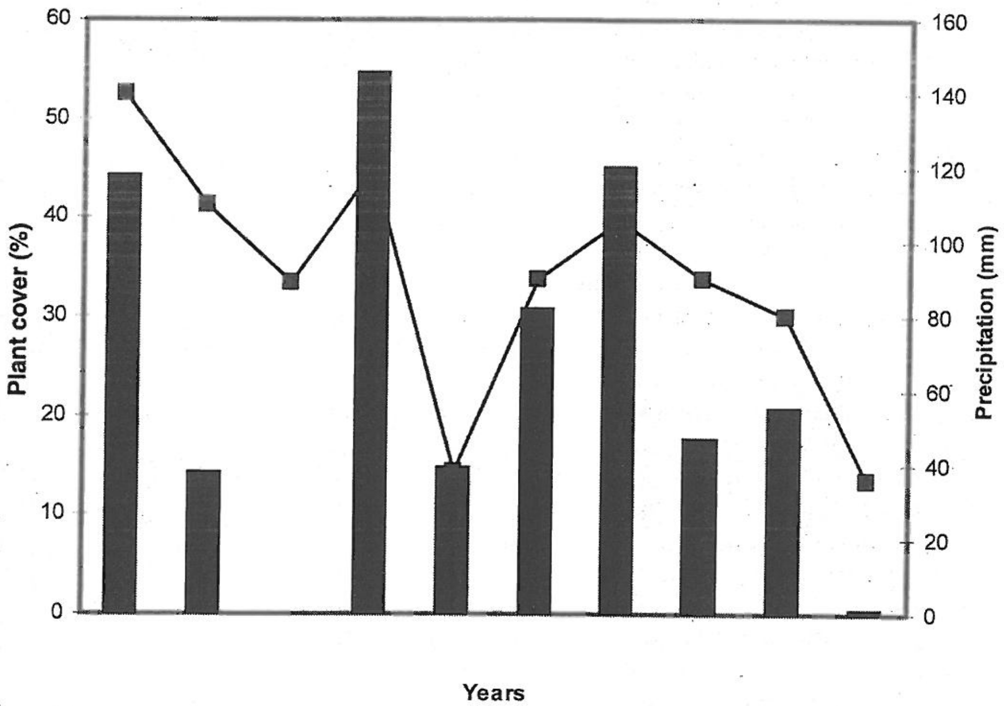

Figure 4. Effects of mean precipitation on cover of *Rhanterium epapposum* at Sulaibiya Experimental Station in Kuwait (Omar, 1991 [21]).

Table 1. Mean percentages of ground coverage in open grazed and protected areas in *Rhanterium steppe* in southwestern Kuwaita.

Parameters[b]	Open grazed area ($n = 120$)			Protected area ($n = 60$)		
	Range (%)	Average (%)	SD	Range (%)	Average (%)	SD
Gravel	3.5–78.5	34.8	26.37	0–38.0	10.5	15.96
Litter	0–14.5	8.8	5.77	10.0–23.0	17.5	5.02
Bare	0–100	33.6	32.58	18–45	29.5	11.10
Vegetation cover	0–35	22.8	10.44	34–53	42.5	8.61
Dominant species (% of total cover)		*C. conglomeratus* (2.6%)			*Rhanterium epapposum* (10%)	

[a]The Quadrat method was used for vegetation assessment in eight sites in the open grazed and four sites in the protected area (Sulaibiya Experimental Station). At each site, 15 1 m^2 quadrats were assessed for gravel, litter, bare and total vegetation cover. Data were analysed by *t*-test.

[b]Vegetation cover and litter percentages were significantly higher in protected sites rather than in open-grazed sites, whereas the gravel percentage was higher in open-grazed sites than in protected sites, and there was no difference in the percentage of bare at $p \leq 0.05$.

Al-Bahra, Al-Mutla and Sulaibiya the stocking rates were 2.15, 1.83 and 1.4 ha/AU, respectively [24]. Stocking densities in arid rangelands recommended were between 17.5 ha/AU to 55 ha/AU with an average of 33 ha/AU [24].

There have been numerous studies that have proven the detrimental effects of poor grazing practices. One of these studies considered heavy stocking as a prime factor for the undesirable vegetation changes in the southwestern semi-desert rangeland in the USA [25]. Studies conducted at the Kuwait Institute for Scientific Research (KISR) showed that the grazed areas had 53% less plant cover and 3.3 times greater bare ground than protected areas (table 1). Consequently, herbage production would be substantially lower in the open-grazed areas. Plant species like *Rhanterium* which are more palatable are heavily used up to 90% [22,26]. In addition to the direct effects of grazing, large herds of livestock, particularly the sheep, trample the soil surface. This leads to severe soil compaction, reduction in infiltration capacity and loss of soil resources through wind erosion. Such heavy grazing drastically affects plant development and seed production.

Off-road traffic. In Kuwait, there has been a dramatic increase in off-road driving during the past decades. Off-road movement of vehicles has long been recognized as a major deleterious factor causing widespread damage to the vegetation and causing tracks on the soil surface. Apart from obvious damage to shrubs, vegetation is also affected, as soil compacts in the tyre tracks. Soil compaction reduces the ability of the soil to hold water and decreases pore space. The penetration resistance of compacted soils on drying compared to an uncompacted soil increases manifold.

The roots on compacted soils encounter considerable difficulty in penetrating the surface layer [27] with noticeable repercussions for seedling establishment and growth. However, depressions caused by single passage tracks on the desert surface could provide a favourable microclimate for seed germination and establishment. Hence, species richness and density particularly of annuals were much greater in such depressions [28].

Spring camping and recreation. Spring camping in open desert areas, a traditional practice that takes place during October to April, closely follows overgrazing as the second most important mechanism of land degradation in Kuwait. It leads to soil loss due to excavation, clearance of natural vegetation around the camp, severe soil compaction, reduction in soil infiltration capacity and deterioration in wildlife habitat [26]. Restricted camping areas cover military, oil production, and metropolitan areas. All other lands are open for camping and grazing. The garbage left behind by the public poses a serious environmental threat in the desert.

Dumping of garbage in the desert. Management of ever-increasing quantities of wastes is an environmental challenge in Kuwait. According to Abdulla and Mahrous [29], the total solid wastes generation in Kuwait is estimated to be more than four million tons per year, which includes approximately one million tons (25%) of household wastes. Approximately, 2–3 million tons of construction and demolition wastes (C and D) wastes are produced each year [30]. These are usually disposed of in domestic waste pits, which were subsequently dumped in decommissioned gravel and sand quarries and in landfills sites in the desert [31]. This practice places a huge burden on the desert.

Dumping sites negatively impact the native vegetation by serving as reservoirs for runoff water during the rainy season leading to hydrological disruption or acting as drainage holes for shallow ground water aquifers thereby depleting soil moisture in the surrounding area. The heavy machinery used in dumping operations causes severe soil compaction and adversely affects native plant growth.

Gulf War effects on native vegetation. The invasion and occupation by Iraq exposed Kuwait's native vegetation to tremendous pressure imposed by oil pollution (oil soot, oil mist and oil spills) and military activities, such as placement of millions of land mines by the Iraqis, development of thousands of ditches, ducts, and bunker shelters and personnel carrier movement and related chemical pollution such as heavy metals. KISR has conducted a number of studies to assess the impact of oil pollution on plants' availability, survival percentage, ground cover, species frequency and density, morphology, phenology and herbage production [1,10,32–37].

These studies have shown that all native plants were killed in areas inundated with oil (oil-logged) in all study areas. The herbaceous plants were affected more than the perennial species. The plants with underground reproductive organs (*Cyperus conglomeratus, Gynandries sisyrinchium, Dipcadi erythraeum* and *Stipagrostis plumosa*) could regenerate to a varying extent in soot and oil mist covered areas. However, *Rhanterium epapposum* failed to survive, regenerate and set seed. Even the seed germination was affected. Herbage production was adversely affected in different categories of oil pollution, with oil logged and oil-mist covered areas having no herbage biomass. Negative effects were also evident in vegetation structure, species composition and the productivity of native vegetation in polluted areas. High levels of heavy metals and hydrocarbons were detected in plants covered with oil-mist and oil-spills areas [36].

Several vegetation attributes were measured in damaged areas, such as percentage cover, density and herbage production. Results of vegetation assessment indicated that even after more than a decade since the detonation of oil wells, the impact of oil pollution on vegetation cover and herbage production is significant (table 2). The areas categorized as clean (areas showing no soot or oil pollution on the soil) and areas covered with soot contained higher vegetation cover and were dominated by *Stipa capenses* and *Filago spicata*. The tar mat, dry oil lake and wet oil lake had either very minimal or no vegetation covers. Litter was more abundant in clean, sooty and tar mat areas. Most of the bare ground (without vegetation, litter or gravel) was recorded in dry oil lakes and oil lakes [1].

Table 2. Vegetation cover and herbage production under five oil pollution categories in As-Sabriyah/Ar Rawdatayn areas in Kuwait.

Parameters	Oil pollution categories				
	Clean	Soot	Tar mat	Dry oil lake	Wet oil lake
Bare	14.6c*	12.3c	42.5b	80.8a	88.0a
Gravel	17.0b	27.5ab	38.5a	16.9b	9.2b
Litter	24.5a	13.3ab	5.0bc	2.4c	2.8c
Total vegetation	43.8a	46.8a	14.0b	0.0b	0.0b
Herbage Production (kg/ha)	392a	245ab	192ab	0b	0b

*The values followed by the same alphabet within the same row are not statistically different at $p \leq 0.05$.

Thousands of tons of sulphur and nitrogen oxides and polycyclic aromatic hydrocarbons (PAH) were emitted daily into the atmosphere along with soot. Partially combusted oil droplets had devastating effects on desert plants. These atmospheric pollutants were shown to activate promutagens into mutagens [38–41]. Malallah *et al.* [40] investigated the genotoxic effects of oil pollution in some native desert plants and reported increased anther sterility, occurrence of meiotic irregularities and inhibition of growth.

After the liberation war (1991), a major environmental concern was the disposal of tremendous amounts of unexploded ordinance, landmines and military vehicles and equipment left behind by the retreating Iraqi army. There were also some concerns by the Government of Kuwait on the presence of Depleted Uranium (DU). A study was conducted by the International Atomic Energy Agency (IAEA) to assess DU in water, soil and vegetation in some locations in Kuwait. Their results showed very small residues in the order of a few microSieverts, well below the annual doses received by the population of Kuwait from sources of natural radiation in the environment. Thus, there has been no need for remedial action in this respect [42].

These solid wastes from the war were cleaned up and placed in giant piles in the desert. While the unexploded ammunitions and land mines were disposed of properly, the military equipment and rubble still remain at several places in the desert and pose a risk to the environment.

Before the Iraqi invasion, the desert flat sub-habitat in the Sabah Al-Ahmad Nature Reserve hosted a wide range of plant species. *Rhanterium epapposum* (in the west) and *Haloxylon salicornicum* (in the northeast) were the major perennial shrub communities [43]. The construction of bunkers and foxholes, placement of mines and increased vehicular movement during the 1990–1991 occupation by Iraq severely damaged the Nature Reserve's infrastructure, land, native vegetation and wildlife habitats. The physical and chemical characterization of soil samples from different damage types indicated serious disruption of pedogenic processes in the soil profile and alterations in a number of soil properties. The composition, abundance and coverage of vegetation were also negatively impacted by military activities. The effects of different damage types on soil and vegetation properties was scored on an impact rating scale from 0 (no impact) to 4 (severely impacted). Areas covered by refilled foxholes, refilled ridges and compacted areas between foxholes and under road tracts were severely damaged, whereas the low-lying sandy areas created by erosion of loosened topsoil was moderately damaged.

Gravel quarrying. A large area in Al-Mutla area in the northern part of Kuwait was used for gravel mining. This activity has caused rupture of lag cover, soil displacement, landscape disruption, and soil compaction due to off-road movement of vehicles, dust fall out and vegetation degradation [44]. Gravel quarrying has destroyed the soil and native vegetation, of which *Rhanterium* was the dominant shrub species.

Development of irrigated agriculture. A large area in the southern part of Kuwait (Wafra) has been developed for irrigated crop production both in the open and under protected structures. For more than a decade, farmers have been using brackish groundwater and desalinated seawater for irrigation. The vegetation map prepared prior to the development of agricultural activity showed the dominance of the *Rhanterium epapposum* community in this area [9]. But, a more recent study indicates a major shift in plant community from *Rhanterium epapposum* to *Cyperus conglomeratus* and *Stipagrostis plumosa* [10,45]. At present, the annual forbs dominate species composition.

6. Restoration and revegetation measures for *Rhanterium epapposum*

Because desert ecosystems like that of Kuwait are not very productive in terms of biomass production per unit area, there is an immediate need to manage them sustainably by establishing a balance between productivity and use. A few studies have been conducted on the potential for vegetation recovery in damaged *Rhanterium* ecosystems in northern Arabia [21,22,26,46,47]. Overgrazing is perceived as the major cause of desertification and loss of vegetation in Kuwait [22,26]. However, other factors such as the nature of the substrate, soil compaction, rainfall characteristics, build-up of the seed bank in the soil and vegetative regeneration potential have considerable consequences for plant restoration.

Under Kuwait's conditions, deep sandy and loamy sand substrates favour good plant growth particularly in *Rhanterium epapposum* due to the fact that they allow deep percolation of rainwater. The surface layer after drying acts as insulation against evaporation from subsurface layers. This increases the amount of water available in the root zone. But, the sandy soil is effective in retaining moisture and promoting plant growth only when the surface soil layer is not lost through wind or water erosion. Le Houerou [48] also reported better vegetation recovery in sandy soils than in compacted soils. In contrast, compact layers (formation of soil crust or compacted by off-road traffic) favour greater surface runoff and this, apart from removing whatever little thin film of loose soil may remain, washes seeds that are deposited on the surface. Regeneration of *Rhanterium epapposum* is greatly improved in sandy depressions.

A number of studies conducted by the senior author have confirmed that long-term drought can alter vegetation as dramatically as overgrazing. This contradicts the commonly held view that cessation of grazing and deleterious human activities will improve range conditions significantly [21,22,45]. Rainfall distribution is also critical for vegetation recovery. *Rhanterium* seed germination takes place only during years with individual rain events in excess of about 30 mm [47]. Therefore, under arid conditions, supplemental irrigation improves seed germination, seedling establishment and plant cover when rainfall is either inadequate or distributed unevenly [21,23,43]. In contrast, new shoots are produced from the underground shoots after the receipt of moderate precipitation, although further plant development and biomass production are dependent on the total and even distribution of rainfall and protection from grazing.

Deep sandy soils, protected from wind and water erosion, allow substantial build-up and retention of seed banks. This acts as a buffer against adverse conditions for plant growth and seed production. These seeds germinate when favourable conditions return, based on observations made by the authors in the SES. *Rhanterium* plants have the ability to build up a large seed bank in the soil, and seeds can remain viable for four years or more [12]. In contrast, minute seeds are blown away in compacted or crusted surfaces. Even if the seeds are present, these sites do not allow seeds to be properly oriented. This is crucial for germination to occur in this species [46]. Seed germination in *Rhanterium* under field conditions is very low (1–2%) and varies considerably from one lot to another. Recent KISR studies have shown that germination of *Rhanterium* seeds can be increased from 1 to 34% by pre-chilling the seeds for 90 days at 4°C and then germinating at 18°C [12]. Therefore, it is desirable to germinate the seeds in the laboratory, and then to transplant the hardened seedlings in the desert during the favourable season (winter).

Rhanterium epapposum has an excellent potential for vegetative regeneration from subterranean stumps. Stumps in heavily grazed, sandy areas can still produce new shoots every year to prevent the shrub from drying completely. Protecting the site from grazing can greatly enhance vegetative regeneration in a short period of time [46,47].

Based on studies conducted by the authors at KISR, the following strategy has been suggested to restore the *Rhanterium epapposum* community in Kuwait [43]:

- Reduce or eliminate the causes of degradation (overgrazing, off-road traffic, pollution, etc.).
- Initiate soil improving process (reduces soil erosion, improve soil organic matter, nutrient status).
- Undertake measures to improve microsite water availability and nutrient cycling (reduce runoff, improve soil infiltration capacity by pitting, ripping, terracing, establishing microcatchments).
- Reduce detrimental ecosystem interactions while increasing synergies among ecosystem components (establish key species and ameliorate micro-environmental conditions, reducing inter species competition, integrating soil, vegetation and landscape level strategies).

The above strategy will require establishment of protected areas, adoption of efficient propagation and growing techniques and undertaking revegetation programs using the latest soil and water conservation techniques.

7. Establishment of protected areas for restoring *Rhanterium epapposum* community

Although subterranean stumps manage to produce sufficient quantities of new shoots each year, intensive grazing will prevent flowering and seed production. Therefore, protection of areas from grazing by the establishment of enclosures would allow plants to recover sufficiently, in order to flower and set seed. Protected areas in the *Rhanterium epapposum* ecosystems could provide a genetic source for future large-scale rehabilitation projects. Studies conducted at KISR have suggested that the recovery of the *Rhanterium* community can be accelerated by protecting the area from grazing and detrimental human activities [21,27]. This fact was proven by studies conducted at the SES during the 10 years of protection prior to the Iraqi invasion, as presented in table 3 [21].

In 1997, approximately 20 km^2 was fenced off to form an exclosure to protect Sabriya oilfield in the northeast of Kuwait. Since then, access to this area has been restricted, and all detrimental activities halted. Before the exclosure was created, perennial woody shrubs were almost absent or overgrazed in the area. The vegetation cover, biomass production, and species diversity inside the exclosure was compared with that in the area outside the exclosure and the SES. The recovery of perennial shrub vegetation, especially *Rhanterium*

Table 3. Contribution of *Rhanterium epapposum* to botanical composition during the ten year protection at Sulaibiya Experimental Station.

Species	Average composition during the year								
	79–80	80–81	82–83	83–84	84–85	85–86	86–87	87–88	88–89
R. epapposum[a]	14.5	5.7	13.0	65.0	8.4	5.0	3.3	6.4	90.3
Total shrublets[b]	14.6	13.0	13.0	65.0	8.4	5.0	3.3	6.4	90.3
Annual grasses	19.9	4.3	10.1	0.6	15.3	6.5	7.1	9.1	1.6
Perennial grasses	3.8	3.5	0.6	8.0	0.1	0.0	0.0	0.2	0.0
Perennial forbs	0.4	0.9	0.8	0.0	0.2	0.0	0.1	0.6	0.0
Annual forbs	61.2	78.3	75.5	26.5	76.1	88.5	89.2	83.4	8.1
Annual precipitation (mm)[c]	140	110	120	38	90	106	90	80	36

[a]Percent of the total coverage.
[b]Main contributors: Shrublets: *Rhanterium epapposum*; annual grasses: *Cutandia memphitica* and *Schismus barbatus*; perennial grasses: *Cyperus conglomeratus*; perennial forbs: *Fagonia glutinosa* and *Polycarpea repens*; annual forbs: *Astragalus schemperi, Atractylis cardatus, Ifloga spicata, Koelpinia linearis, Lotus halophilus, Moltkiopsis ciliate, Plantago* spp., and *Schimpera arabica*.
[c]Average annual precipitation in Kuwait is 106 mm.

epapposum was very striking, with cover values for both shrubs and annuals closely comparable to that at the SES [46]. However, most of the new *Rhanterium* plants in the Sabriya exclosure were from underground woody stumps and no new seedlings appeared during the four years of protection (1997–2001), as compared to 252 seedlings recorded in the 10 quadrats (area of each quadrat being 0.25 m^2) at the SES.

These exclosures provide opportunities for conducting plant succession studies and for demonstrating the type and amount of vegetation, which a sector of land can support under undisturbed conditions. In other words, they are required for long-term research and rangeland inventory assessment. Exclosures established in areas where there are sparse living stands of desirable species can be useful in the conservation of habitats and wildlife, investigation on succession, and preserving a natural history in a country [21]. Nevertheless, they should not be considered as sole techniques/tools for rangeland improvement.

8. Seed collection, mass propagation and seed germination

A major problem in these revegetation studies is the dearth of seeds and seedlings. Therefore, field trips are being conducted to different areas in Kuwait to collect seeds and vegetative propagules from natural populations of *Rhanterium epapposum*. All freshly harvested seeds were dried, cleaned and properly stored. Protocols for mass propagation of *Rhanterium* using seed and tissue culture techniques have been developed by KISR and can be used in large-scale revegetation efforts [12,49].

9. Re-vegetation trials and ecosystem monitoring

During 2000–2001, KISR undertook two pilot revegetation studies (one area was impacted by military activities and the other was used for detonation of munitions in large underground pits) in war-affected areas of Sabah Al-Ahmad Nature Reserve. Hardened seedlings of naturalized species and seed mixes containing various native species were used to restore the native plant communities of the area. Protective irrigation was given to improve seed germination and seedling establishment. The success of the revegetation program was assessed by undertaking a vegetation survey in revegetated, nonrevegetated and undisturbed (e.g. SES) areas. These revegetation programs were very effective in improving species richness, biomass production and facilitating recovery of native species such as the *Rhanterium epapposum* [43].

10. Conclusions

In Kuwait, *Rhanterium epapposum*, which is mainly found in the northern part particularly in deep sandy soils, provides essential forage for livestock grazing. It is associated with some highly palatable species such as *Cutandia memphitica* and *Plantago boissierri*. At present, the densest stands of *Rhanterium epapposum* with an estimated coverage from 15 to 25% occur only at the KISR's SES. The community was significantly altered in coverage from 30.6% (1974) to 2.1% (2001). This has been caused by environmental and human factors such as: persisting drought; overgrazing by livestock; off-road vehicle use; camping and recreation; war and military activities; gravel quarrying; and expansion in irrigated agriculture.

Rhanterium epapposum being the national plant of Kuwait and one of the two climax plant species, its restoration is central to maintaining cultural heritage, ecological integrity, conservation of wildlife habitat and species, environmental sustainability and preserving recreation opportunities. Because Kuwait's native vegetation represents a transition between semi-desert and desert vegetation and is highly tolerant to harsh environmental conditions such as extreme temperatures, drought and salinity, *Rhanterium epapposum* can serve as a valuable gene source for crop improvement programs with far reaching socio-economic and scientific benefits. Additionally, Kuwait is a signatory to the Convention on Biological Diversity (CBD). Under Article 10 of the convention, Kuwait is required to adopt measures to conserve and maintain the potential of natural biodiversity to meet present and future human needs. In this respect, the State of Kuwait represented by the Public Authority for Assessment of Compensation (PAAC) is taking necessary steps to rehabilitate the environmental damages in accordance with the decisions of the United Nations' Compensation Commission (UNCC). The environmental claims deal with rehabilitation of groundwater, terrestrial environment, marine and coastal areas, and public health. Currently, a comprehensive rehabilitation plan is being prepared by PAAC and will be implemented in the near future to rehabilitate areas damaged by war and military activities following technical recommendations by the UNCC.

Although *Rhanterium epapposum* has good potential for vegetative regeneration from subterranean stumps, seed germination takes place only during years with individual rain events in excess of 30 mm. Seeds can be stored for more than four years, and germination can be induced during favourable conditions. Protection from grazing and good soil moisture conditions can significantly improve the status of vegetation in the *Rhanterium epapposum* community type in Kuwait. Protection has been shown to increase biomass production significantly. Since restoration of a degraded ecosystem in arid lands needs to be carried out over a long period of time, normally not less than five years, a database should be developed to monitor the progress of succession and performance of different plant species.

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References

[1] Omar, S.A.S., Misak, R., Bhat, N.R., Shahid, S.A. and Delima, E.C., 2003, Assessing damage magnitude and recovery of the terrestrial ecosystem. Follow up of natural and induced recovery. Kuwait Institute for Scientific Research, Report No. KISR 7105, Kuwait.
[2] Dickson, V., 1955, *The Wildflowers of Kuwait and Bahrain* (London: Allen and Unwin), pp. 5–62.
[3] Kernick, M.D., 1966, *Plant Resources, Range Ecology and Fodder Plant Introduction*. Report to the Government of Kuwait, FAO, TA 181, Mimeograph.
[4] Halwagy, R. and Halwagy, M., 1974, Ecological studies on the desert of Kuwait. I: the physical environment. *Journal of the University of Kuwait (Science)*, **1**, 75–86.
[5] Omar, S.A.S., Al Mutawa, Y. and Zaman. S., 2000, *Vegetation of Kuwait* (Kuwait: Kuwait Institute for Scientific Research), pp. 159.
[6] Dickson, V. and Macksad, A., 1973, *Plants of Kuwait* (Kuwait: Ahmadi Natural History and Field Studies Group Kuwait), pp. 12–18.
[7] Omar, S.A.S., 1982, Baseline information on native plants of Kuwait. Kuwait Institute for Scientific Research Technical Report No. KISR 1790, Kuwait.
[8] Boulis, L. and Al-Dosari, M., 1994, Checklist of the flora of Kuwait. *Journal of the University of Kuwait (Science)*, **21**, 203–218.
[9] Halwagy, R. and Halwagy, M., 1974, Ecological studies on the desert of Kuwait. II: the vegetation. *Journal of the University of Kuwait (Science)*, **1**, 87–95.
[10] Omar, S.A., Misak, R., King, P., Shahid, S., Abo-Rizq, H., Grealish, G. and Roy, W., 2001, Mapping the vegetation of Kuwait through reconnaissance soil survey. *Journal of Arid Environments*, **48**, 341–355.
[11] Vesey-FitzGerald, D.F., 1957, The vegetation of eastern and central Arabia. *Journal of Ecology*, **45**, 779–798.
[12] Zaman, S., 2006, Establishment of seed bank unit for native plants of Kuwait. Kuwait Institute for Scientific Research Report No. KISR 8536, Kuwait.
[13] Stoddart, L.A. and Smith, A.D., 1955, *Range Management*, 2nd edn (London: McGraw-Hill).
[14] Stoddart, L.A., Smith, A.D. and Box, T.W., 1975, *Range Management* (London: McGraw-Hill).
[15] Westoby, M., Walker, B. and Noy-Meir, I. 1989, Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, **24**, 266–274.
[16] Omar, S.A., Alsudirawi, F., Agrawal, V., Hamdan, L., Al-Bakri, D. and Al-Shuaibi, F., 1986, Criteria for development and management of Kuwait's First National Park/Nature Reserve. **Vol: 1.** Inventory and zoning. Kuwait Institute for Scientific Research Report No. KISR 2164, Kuwait.
[17] Khalaf, F.I., 1989, Desertification and aeolian processes in the Kuwait desert. *Journal of Arid Environments*, **16**, 125–145.
[18] Brown, G., 2002, Species richness, diversity and biomass production of desert annuals in an ungrazed *Rhanterium epapposum* community over three growth seasons in Kuwait. *Plant Ecology*, **165**, 53–68.
[19] Omar, S.A.S., 1990, Desertification in the eastern region of Arabian Peninsula. The case study of Kuwait. PhD dissertation, University Microfilms International, California, USA.
[20] Omar, S.A.S. and Zaman, S., 1998, Kuwait's rangeland status, development, and research priorities, in: S.A.S. Omar, R. Misak, D. Al-Ajmi and N. Awadhi (Eds) *Sustainable Development in Arid Zones: Management and Improvement of Desert Resources. Vol. 2* (The Netherlands: A.A. Balkema), pp. 402–420.
[21] Omar, S.A.S., 1991, Dynamics of range plants following 10 years of protection in arid rangeland in Kuwait. *Journal of Arid Environments*, **21**, 99–111.
[22] Zaman, S., 1997, Effects of rainfall and grazing on vegetation yield and cover of two arid rangelands of Kuwait. *Environmental Conservation*, **24**, 344–350.
[23] Omar, S.A., Misak, R., Shahid, S.A., Malik, R., Madouh, T. and Abo-Rezq, H., 2001, Rehabilitation and management of Kuwait's rangelands for sustainable yield. Kuwait Institute for Scientific Research Report No. KISR 6087, Kuwait.
[24] Razzaque, M.A., Taha, F.K. and Sulaiman, A.R., 1990. Performance of three breeds of Arabian sheep under Kuwait's rangeland conditions, in: R. Halwagy, F.K. Taha and S.A. Omar (Eds) *Advances in Rangeland Management in Arid Zones* (London: Kegan Paul International), pp. 188–200.
[25] Martin, S.C., 1975, Stocking strategies and net cattle sales on semi desert range. US Department of Agriculture, Forest Service Research Paper RM-146.
[26] Misak, R., Al-Awadhi, J.M., Omar, S.A.S. and Shahid, S.A., 2002, Soil degradation in Kabd area, southwestern Kuwait City. *Land Degradation and Development*, **13**, 403–415.

[27] Taylor, H.M. and Gardner, H.R., 1963, Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. *Soil Science,* **96,** 153–156.

[28] Brown, G. and Schoknecht, N., 2001, Off-road vehicles and vegetation patterning in a degraded desert ecosystem in Kuwait. *Journal of Arid Environments,* **49,** 413–427.

[29] Abdulla, A.M.M. and Mahrous, F., 2001, Recycling of municipal solid waste in the State of Kuwait. *Arabian Journal of Science and Engineering,* **26,** 3–10.

[30] Kartam, N., Al-Mutairi, N., Al-Ghusain, I. and Alhumoud, J., 2002, Recycling of construction and demolition wastes in Kuwait, in: *Proceedings of Joint CSCE/ASCE International Conference: An International Perspective on Environmental Engineering,* 21–24 July 2002, Niagara Falls, ON, Canada,. ISBN:0-88955-532-X, p. 1017.

[31] Alhumoud, Jasem M., 2002, Solid waste management in Kuwait. *Journal of Solid Waste Technology and Management,* **28,** 97–105.

[32] Omar, S.A., Shahid, S.A., Misak, R., Grealish, G. and Bhat, N., 2000, Assessing damage magnitude and recovery of the terrestrial ecosystem/follow up of natural and induced desert recovery. Kuwait Institute for Scientific Research Report No. KISR 6088, Kuwait.

[33] Zaman, S., 1998, Impact of the Gulf War on Kuwait's desert flora and soil, in: S.A.S. Omar, D. Al-Ajmi, R. Misak and N. Al-Awadhi (Eds) *Sustainable Development of Arid Zones: Assessment and Monitoring of Desert Ecosystems. Vol. 1* (The Netherlands: Balkema), pp. 69–82.

[34] Omar, S.A.S. and Zaman, S., 1995, Post war rangeland status of Kuwait, in: N. E. West (Ed.) *Rangelands in Sustainable Biosphere: Proceedings of Fifth International Rangeland Congress,* pp. 414–415.

[35] Omar, S.A. and Eldin, A.S., 1990, Range research casualty of Gulf Crisis. *Rrail Boss. Society of Range Management. Range Management.* News Supplement, November.

[36] Zaman, S. and Alsdirawi, F., 1993, Assessment of Gulf environmental crisis: impacts on Kuwait's desert renewable natural resources. Kuwait Institute for Scientific Research Report No. KISR 4247, Kuwait.

[37] Al-Houty, W., Abdal, M. and Zaman, S., 1993, Preliminary assessment of Gulf War on Kuwait desert ecosystem. *Journal of Environmental Science, Health,* **A28,** 1705–1726.

[38] Malallah, G.A., Afzal, M., Attia, T.A. and Abraham, D., 1996, Tapetal cell nuclear characteristics of some Kuwait desert plant. *Cytologia,* **61,** 259–267.

[39] Malallah, G.A., Afzal, M., Gulshan, S., Abraham, D., Kurian, M. and Dhami, M.S.I., 1996, *Vicia faba* as a bioindicator for oil pollution. *Environmental Pollution,* **92,** 213–217.

[40] Malallah, G.A., Afzal, M., Mutin, G., Murin, A. and Abraham, D., 1997, Genotoxicity of oil pollution of some species of Kuwaiti flora. *Biologia,* **52,** 61–70.

[41] Malallah, G.A., Afzal, M., Kurian, M., Gulshan, S. and Dhami, M.S.I., 1998, Impact of oil pollution on some desert plants. *Environment International,* **24,** 919–924.

[42] IAEA, 2002, International Atomic Energy Agency. Executive Summary Report. Available online at: http://www.iaea.org/NewsCenter/News/2003/13-571089.shtml accessed November 2007.

[43] Omar, S.A., Bhat, N.R., Shahid, S.A. and Asem, A., 2005, Land and vegetation degradation in war-affected areas in the Sabah Al-Ahmad Nature Reserve of Kuwait: a case study of Umm. Ar. Rimam. *Journal of Arid Environments,* **62,** 475–490.

[44] Al-Awadhi, J.M., 2001, Impact of gravel quarrying and urbanization on earth surface processes in Kuwait. *Environmental Geology,* **41,** 365–371.

[45] Omar, S.A.S., Madouh, T., El-Bagouri, I., Al-Musselem, Z. and Al-Telaihi, H., 1998, Land degradation in arid irrigated area: the case of Wafra in Kuwait. *Land Degradation and Development,* **9,** 283–294.

[46] Brown, G. and Al-Mazrooei, S., 2003, Rapid regeneration in a seriously degraded *Rhanterium epapposum* community in northern Kuwait after 4 years of protection. *Journal of Arid Environments,* **68,** 387–395.

[47] Brown, G., 2002, Community composition and population dynamics in response to artificial rainfall in an undisturbed desert annual community in Kuwait. *Basic Applied Ecology,* **3,** 145–156.

[48] Le Houerou, H. N., 1986, The desert and arid zones of northern Africa, in: M.I. Evanari, I. Noy-Meir and D.W. Goodall (Eds) *Ecosystems of the World* (Amsterdam: Elsevier), pp. 101–147.

[49] Sudershan, C., AboEl-Nil, M. and Hussain, J., 2000, Tissue culture technology for the conservation and propagation of certain native plants. *Journal of Arid Environments,* **54,** 133–147.