United Nations
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Programme

INNOVATIVE WAYS FOR A SUSTAINABLE USE OF DRYLANDS

FINAL REPORT OF THE SUMAMAD PROJECT









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Preface

In the past, many dryland areas over the world have been considered as 'wastelands' as they are often characterized through their scarce water resources, poor organic soils, low biological productivity, and extreme climatic conditions. Inhabited by relatively few human beings and often located in remote and peripheral areas, far away from the decision-making capitals, drylands have not always received the political attention they deserve. And yet, drylands are important ecosystems in their own right providing habitats to species that are well adapted to their harsh environments. Moreover, drylands provided the spiritual settings for the origins of three of the major world religions.

Fortunately, drylands have moved more into the centre of attention thanks to the United Nations Convention to Combat Desertification which has been agreed upon by the international community in 1994. UNESCO, with its 'Arid Zones' Programme launched already in the 1950s as an international and interdisciplinary research endeavour, has helped to pave the way for the recognition of the importance of drylands.

This is why UNESCO and the United Nations University (UNU) joined forces to elaborate the Sustainable Management of Marginal Drylands (SUMAMAD) Project in late 2001. Our aim was to create an inter-regional research cum development project so that expertise on dryland management can be shared among scientists and natural resources managers the world over. Thanks to generous funding provided by the Flemish Government of Belgium to UNESCO, the SUMAMAD Project started in 2002 in its first phase, and has completed its second phase in 2013 by involving dryland specialists from Belgium, Bolivia, Burkina Faso, China, Egypt, India, the Islamic Republic of Iran, Jordan, Pakistan and Tunisia.

The purpose of the project was not to create new dryland research institutions, but to further enable existing dryland study centres, universities and biosphere reserve managers to conduct their applied research on the ground in the respective partner countries. All the study teams involved in the SUMAMAD Project have brought an invaluable store of knowledge to the fore on how drylands can be managed more sustainably. Improved methods for

water and soil conservation were key for the success of the project. Even more important was to work with and to outreach to local dryland dwellers so that their needs and aspirations could be incorporated into improved land management schemes. At every project site, alternative income opportunities for people have been worked out pending on the specific socio-economic conditions of the area. The need for the diversification of dryland economies can be considered as one of the main outcomes of the project and many examples can be found in this publication.

UNESCO's role in overseeing the project was greatly facilitated by UNU's Institute for Water, Environment and Health and benefited from additional scientific inputs provided by Belgian scientists from Ghent University and the Catholic University of Leuven for which we are very grateful. On behalf of UNESCO, I very much wish to thank the people and the Flemish Government of Belgium for providing the financial support for this large-scale project. In particular, I wish to express my deep appreciation to all SUMAMAD partners in the above-mentioned countries for the excellent work accomplished throughout the last 10 years. The spirit of collaboration was such that we referred to each other as members of the 'SUMAMAD family'.

Dr. Thomas Schaaf

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Division of Ecological and Earth Sciences

Secretary a.i.,
Man and the Biosphere (MAB) Programme
UNESCO

Managing Sustainability of New Quinoa Production Systems through Farming Systems Management

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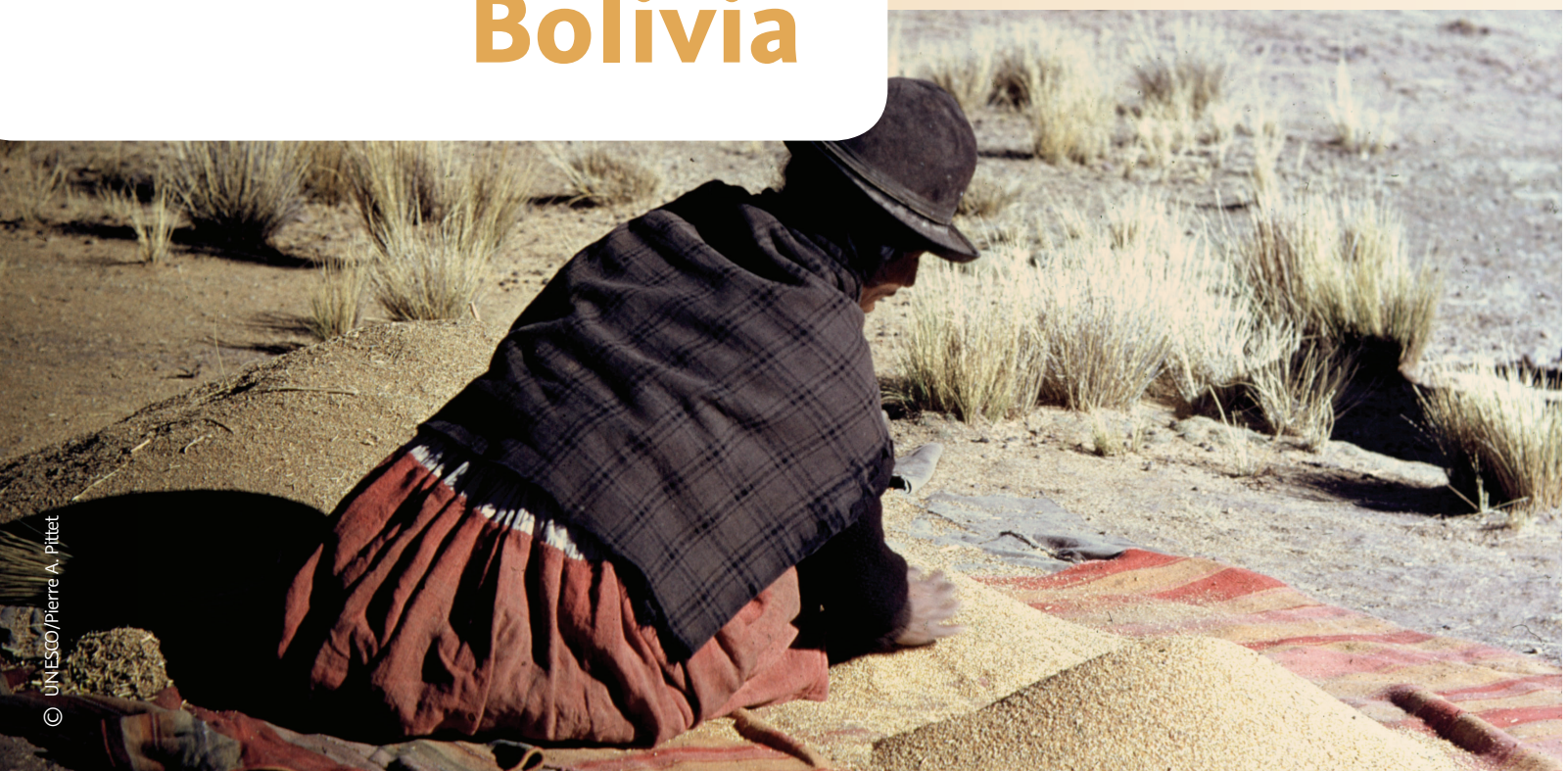


1. Introduction

The Bolivian Altiplano is an 800 km long and 120–160 km wide plateau in South America that runs between the two main ranges of the Andes Cordillera at an average altitude of 4,000 m and a total area of 123,000 km^2. Although the Altiplano covers only 12 per cent of Bolivia's land area (Fig. 1), it contains 35 per cent of its population, including 42 per cent of the urban population and 24 per cent of rural inhabitants. Thanks to its proximity with the equator, it is one of the very few areas in the world where agriculture is practiced at high altitudes. However, low air temperatures and highly variable climatic conditions reduce the cultivation possibilities and crop choices for rural families, reducing their opportunities to accumulate assets and improve their living conditions. Periodic droughts and flooding, as well as the occurrence of severe frosts on average during six months of the year, are characteristic of the climate of the highlands and high plateau regions of Bolivia. In addition to the climate constraints, soils are shallow and show a relatively high sensitivity to erosion processes. In general, the soil materials show a low degree of evolution, attributed to low water availability and the almost permanent low temperatures, which impede pedogenic development and reduce organic material accumulation.

Sustainable agriculture in the Altiplano is based on the ability of individuals (women and men), families and communities to respond to variability through resilient systems. Climate uncertainty and risk have always been part of life in the Altiplano. Farmers have used local ecological knowledge and diverse production systems to cope, adapt and reorganize over time to meet this reality. They have succeeded in several ways thanks to their strong organization and relationship with the environment, including landscape management, agrobiodiversity and strong links within their production systems (Valdivia *et al.,* 2010). However, climate and global change presents a new threat to sustainable farming in the Andes. Climate trends, forecasts and scenario analysis suggest that climate related pressures have increased and will increase further in the Andes, inducing modifications in land use, production systems, indigenous knowledge, coping mechanisms, and livelihood strategies owing to greater year-to-year climatic variation and unpredictability. The frequency of extreme events will likely be greater at high altitudes than in lower areas, and imply losses not equally distributed among or within families, being stronger on the more fragile components (Bradley *et al.,* 2006).

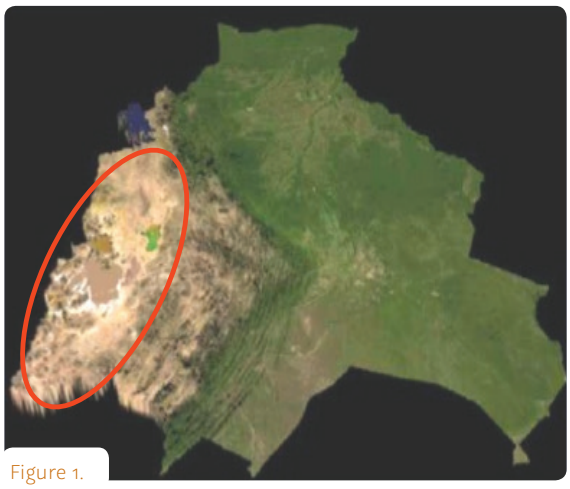


Figure 1.
Map of the Republic of Bolivia. The circle shows the location of the highlands where quinoa is produced (from Miranda, 2012).

The pressure on the environment is not only climatic. Traditional production and management capacity in the Altiplano is also highly disturbed by new socioeconomic conditions. As the urban population increases, more production is required, but a more

intensive production is not well adapted to the fragile environment. Socioeconomic trends are also jeopardizing sustainable long-term agriculture in the Altiplano. Migration, new religions, cultural alienation, and youth indifference are in some cases more damaging than climate risks to local farming systems (Quispe *et al*., 2013).

Although rising temperatures due to climate change enable new crops to grow, showing signs of autonomous adaptation, this also affects the fragile soils, increases the presence of pests and diseases and requires more water, an element that is a source of conflict. As such, in the past decades, rural communities faced difficult conditions that are changing their production protocols and undermining the previously responsive capacity of the population to cope with climate variability. Families (or parts of them) that are losing the capacity to adjust to climate variability migrate to lowlands or cities (Valdivia, 2004).

Few crops can be adequately cultivated with high revenues under the harsh local conditions. One of these, quinoa (*Chenopodium quinoa*), although produced since centuries, has recently been enhanced for export due to its high international prices and for national consumption, given its high nutritional value.

At present, quinoa production is greatly improving the living standards of Altiplano producers and has brought benefits to local families and the country. Local consumption has tripled in the past four years and the grain is included in several social support programmes such as the school breakfast. Internationally, the popularity of quinoa has grown exponentially with 2013 declared by the Food and Agriculture Organization (FAO) as the International Year of Quinoa owing to the potential of the crop to help in the permanent fight against malnutrition.

This shows the importance of looking towards sustainable production systems, especially in production niches. However, the previously traditional production, with somewhat sustainable intercropping and livestock production, is being disturbed by this new trend of intense quinoa production for the market. Intensive production is not well adapted to the environment if not supported by external inputs and requires long fallows to recover natural fertility.

The ancient seeding system, especially in the southern Altiplano was based on a limited soil occupation maintaining most of the original soil surface, without disturbance to prevent erosion (Fig. 2). Facing the year-to-year growing demand for quinoa production, heavy machinery is being used to plough soils, leaving bare surfaces exposed to water and wind erosion. Soil fertility is in many cases no longer restored by long fallow periods because land is needed to satisfy the demand, but it is not replenished by sufficient applications of organic or mineral fertilizers. Since the crop has a high protein quality, nitrogen is extracted from the already poor soils, leaving a trace of unfertile, erosion prone surfaces. Additionally, as quinoa is one of few crops produced with such prices and revenues under the harsh local environment, the tendency towards monocropping is increasing the presence of pests and diseases, which further damages the local production environment. This, however, should not discourage the cultivation of the crop, only we need to further look for alternatives to improve input use, and therefore use the potential of the crop to improve the livelihoods of the local producers and the Bolivian population.

Figure 2.
Above: Traditional quinoa farming with long spaces between plants, little soil surface openings, and large spaces between plants. Below: Mechanized fields.

2. Scenarios for future land use changes

Climate change and socioeconomic pressure are strongly affecting land use in some areas of the Bolivian Altiplano, provoking land use change patterns that might affect the long-term sustainability of the production systems. Although very closely located, local disparities also determine the differences in impacts. The analysis will therefore be restricted to the central and southern Altiplano where quinoa is the main or one of the main crops.

With regard to rainfed agriculture, late onset of the rainy season implies late sowing of the few Andean crops that can be cultivated under the harsh local conditions. In a cold environment such as the Altiplano (even with increasing temperatures), this also implies a high risk of crop failure, since most crops will not reach maturity before the beginning of the next frost season. Late onset of the rainy season could therefore result in the complete or partial failure of the cropping system, which is becoming increasingly common in the area (Garcia *et al*., 2011).

Quinoa production is growing amid the climate and socioeconomic trends, as explained (Fig. 3b). The demand for alternative, exotic, organic food in developed countries has caused a steep and sustained rise in prices. The price of quinoa sold by farmers has more than tripled since 1999, which is currently at US$ 3,600/tonne. This is five times the price of soybean and six times the price of wheat (Blog de quinoa, 2013). Additionally, quinoa presents high resistance and an ability to adapt to the erratic climatic conditions, and is thus a preferred crop compared to other more vulnerable crops.

Interestingly, quinoa production in the region has not necessarily increased because of higher yields but to larger production areas (Fig. 3). In fact, the production area has grown from 12,200 ha in 1970 to more than 70,000 ha in 2012. According to Jacobsen (2011), there are two stages in the trend towards the increasing area. Firstly, from 1970 to 1990, the crop was introduced to the flat areas for the first time (Soraide, 2008), which lead to a yield decrease in the same period. Secondly, from 2000 to the present day, a steadily rising trend has been observed. There was no substantial area increment observed between 1990 and 2000.

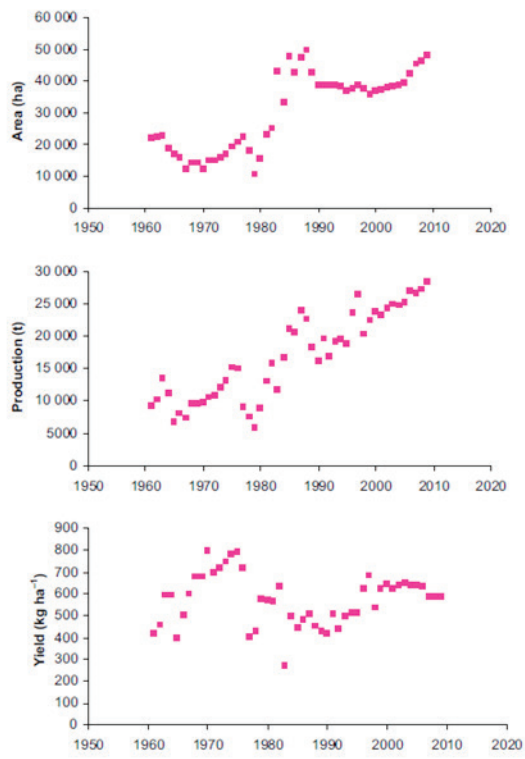


Figure 3.
Production area, production and yield of quinoa in Bolivia (from Jacobsen, 2012).

A continuous land use change in the future towards an increase in quinoa production areas can therefore be expected with certainty, especially if prices continue to rise. Every year, more farmers – not necessarily those traditionally related with quinoa – are attracted to quinoa production. It is expected that this will lead to two problems:

1. The traditional quinoa production zones are intensifying production activities. This means that a production system that used to rely on long fallows, reduced land occupation, diversification, and manual inputs is changing towards a more mechanized, intensively cultivated production system (Cossio, 2008). In order to meet the demand for organically certified products under various private and public labels, the agricultural frontier has been extended, as virgin land on the flat areas is being ploughed, reducing natural vegetation and protection. The increased use of tractors, especially with disc ploughs and sowing machines, has reportedly led to a severe degradation of soil fertility. Fresh manure is used, but, in many cases, it is detrimental to crop growth because in the process of decomposition of manure, it absorbs the limited soil moisture and, in some cases, could release inhibitors that damage the crop. In addition, farmers are opening new lands, which quickly lose their fertility. The organic standards only allow the application of organic fertilizers, effectively restricting fertilization to locally available animal dung. Owing to the scarcity of animal dung in the Altiplano (due to low animal densities), the quinoa production in recent years could only be sustained by soil mining (the consistent net extraction of nutrients from the soil), which together with shortened fallow periods leads to soil degradation.

2. Farmers in non-traditional expansion quinoa production areas are logically attracted to this cereal because revenues are higher than any other crop or livestock activity in the Altiplano. Consequently, landuse in these areas is shifting to quinoa production, endangering crop diversity as other very important crops or livestock production could be abandoned in place of quinoa. Moreover, unsustainable practices could remain unchanged, as lesser knowledge on the production activities also results in a low input system with low yields.

3. Proposals for improved quinoa agriculture in the Altiplano

As mentioned above, the growing use of land for quinoa production has not been accompanied by increasing yields. The National Institute for Statistics of Bolivia reports steady yields between 500 and 800 tonnes/ha since 1980, which was also reported by Jacobsen (2012) and several other authors, although potential reported yields could reach up to 4 tonnes/ha (Choquecallata, 1994).

The gaps between potential and actual yields occur mainly due to lower investment in the different crop inputs. Quinoa is well known locally for its extreme resistance to the harsh environment of the Altiplano, i.e. high drought and frost resistance, production under poor, saline and marginal soils, and very efficient phenological adjustments to external stresses. However, the crop sacrifices yields to rusticity (Bosque, 1998), obtaining quite marginal yields, which in turn, drive farmers to open more lands to satisfy market demands.

In this regard, about eight years ago the Faculty of Agriculture of the Universidad Mayor de San Andrés of La Paz, Bolivia, initiated a thorough evaluation of quinoa production. The aim was to ascertain factors that could substantially increase landuse efficiency with the objective of reducing some destructive trends created by opening up new land for production. It would thus focus on better soil fertility and water management within the production system, while considering quinoa production as an opportunity to reduce the country's poverty and to improve the nutritional level of the Bolivian population, as has been happening in the last decade. The SUMAMAD project aimed to complete and compile the initial knowledge obtained and make it available to decision makers. The following activities were undertaken during the project's implementation.

3.1 Climatic evaluation

An overall assessment of the climate to determine the main climatic constraints for growing quinoa was carried out and – together with previous research – an agroclimatic manual was published. The findings are summarized below:

1. The reduced metabolic activity caused by low mean temperatures result in an increase in the length of the growth period. With a cropping season lasting more than 150 days and longer than the rainy season, mean precipitation below the crop water requirements and a very large coefficient of variation in all Altiplano locations, reduces the chances of successful rainfed production.

2. Frequent delays in sowing and the frequent need to re-sow caused by the high probability of dry spells during and after the normal planting period, results in low yields and crop failure owing to low establishment rate.

3. Prolonged dry spells in February, coinciding with crop sensitive stages such as flowering and grain filling in all Altiplano locations, strongly reduces crop production (Fig. 5a).

4. A general thermal time of 1600 thermal units is necessary for a complete successful cropping cycle, which should be used when planning the habilitation of new production areas.

5. The general reference evapotranspiration strongly increases from north to southwest,

with highest values concentrated in the quinoa production areas. This produces more stress and a reduced chance of a successful, completely rainfed cropping season.

6. Local and ancient knowledge on climate indicators was not neglected and several climate indicators, used locally for early weather forecasts, were identified in the project and published in a calendar. This is valid not only for quinoa production systems, but to support the entire Andean production system. The most remarkable result is the strong relationship between the minimum air temperature in the winter solstice and the total amount of rainfall received during the rainy season (Fig. 5b).

7. A deficit irrigation suitability map was made available for farmers and technicians in Bolivia.

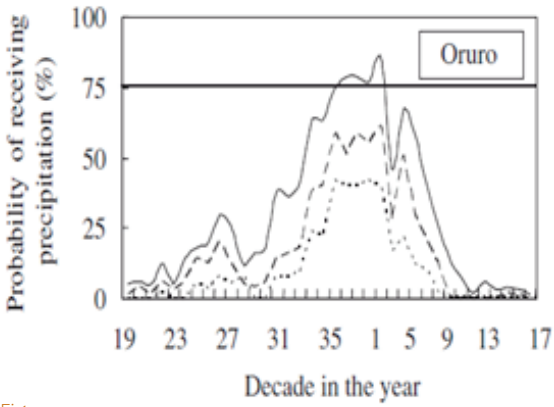


Figure 4a.
Probability of rain on a day > 1mm in a typical Quinoa production location. Notice the strong reduction in probability in February, which coincides with quinoa flowering (from Garcia *et al.*, 2007).

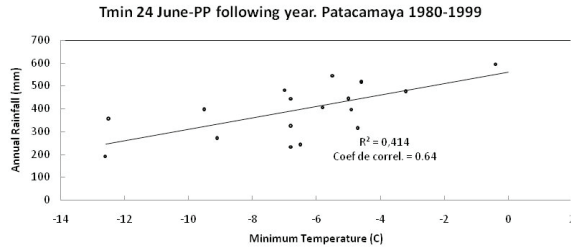


Figure 4b.
Relationship between minimum temperature in winter solstice and quantity of annual rainfall (self-elaboration).

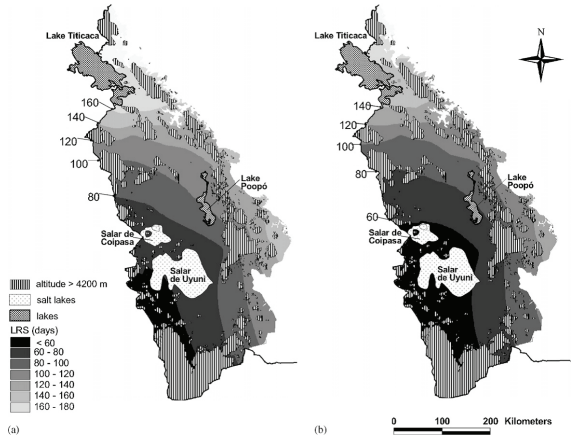


Figure 5.
Geographical representation of the length of the rainy season (LRS) in the Bolivian Altipano in normal (a), and dry (b) years (from Geerts *et al.*, 2006).

3.2 Soil water and fertility evaluation

Water requirements were evaluated not only to find out how much water the crop requires to 'optimally' produce, but mostly to determine the stages of quinoa production that could be more efficient regarding water consumption and transformation into yields. The concept was to apply the idea of 'Deficit Irrigation' with the aim of reducing irrigation events to the most sensitive crop stages, while maximizing Water Use Efficiency (WUE). The results were very

revealing, showing that regardless of the cropping location, the most sensitive stages for successful or at least medium yields were crop establishment (emergence) and flowering.

Moreover, an adequate balance between evapotranspiration before and after anthesis with a larger proportion of water consumed after anthesis, will have a very positive effect on water use efficiency (Fig. 6).

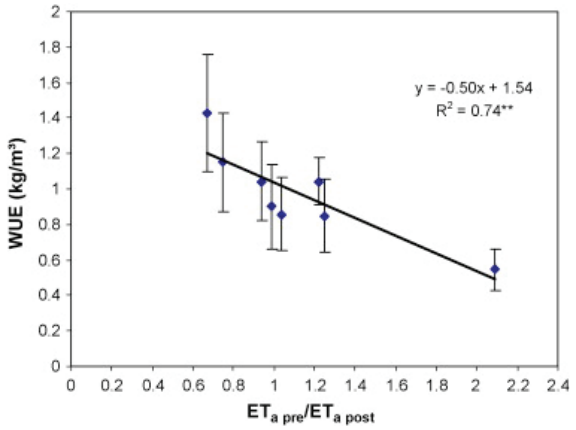
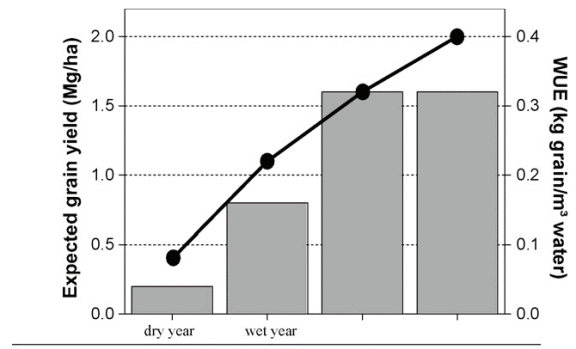


Figure 6a.
Relationship between Water Use Efficiency and pre and post anthesis evapotranspiration rate.



Management	Rainfed agriculture (farmers' conditions)		Full irrigation	Deficit irrigation
Rainfall (mm)	250	450	360	360
Mean Inet (m^3/ha)	-	-	2600	875

Figure 6b.
Relationship between Water Use Efficiency, yield and (Full and Deficit) irrigation requirements (from Geerts *et al.*, 2008).

It was therefore shown, as in other grains, that deficit irrigation with drought stress during the vegetative stages and with ample water supply during germination, flowering and early grain-filling phase yields the highest WUE, without a significant reduction in seed yield. Water stress during flowering and early grain filling has a strong negative effect on yield and WUE. Rainfed cultivation of quinoa during very dry years, results in very poor yields. Hence, deficit irrigation is required to stabilize production along the years. In addition, deficit irrigation allows a better distribution of field labour and decreases the reliance on the rainy season, with less dependence on the market as a consequence. The results provide evidence that use of deficit irrigation with water stress concentrated in the vegetative stages, constitutes a valuable option to stabilize yields of quinoa at high altitudes in the Altiplano, where water resources are limited.

Aside from the interesting results for deficit irrigation, it also became clear that the findings were consistent with guaranteed soil fertility. This means that poor soils with low fertility will not make good use of the water added as 'deficit irrigation', and that the positive impacts of high water use efficiency rates, obtained by managing the balance of evapotranspiration pre/post anthesis, will not be fully expressed under conditions of low soil fertility. As a result, several trials were planned to assess the soil fertility requirements of quinoa, especially regarding nitrogen, which is extremely limited in Altiplano soils, while focusing on organic fertilizer applications.

The results suggest that for Altiplano conditions, it is not only necessary to add fertilizers, but it is also important to draw up a good application calendar, especially if organic manure is applied. Fresh manure applications at the time of sowing or shortly before, produce insignificant differences in yields. This is due to low air temperatures in the area impeding the rapid manure decomposition, which even becomes

a factor of soil water depletion, absorbing water for decomposition and reducing water availability for crops.

Further research was needed on the mineralization rate of manure, because low Altiplano temperatures results in very slow mineralization and use of nitrogen by the crop when it is incorporated just before planting. Two controlled experiments were therefore established to evaluate the rate of mineralization of manure, as follows: a) one was the setting of two large pools of manure from March 2010 to November 2010 to evaluate the rate and efficiency of decomposed nitrogen mineralization prior to incorporation in the field plots; and b) laboratory experiments carried out in incubation chambers to evaluate the mineralization rate of nitrogen and carbon when manure is incorporated into the soil.

The first conclusion was that following the manure application on Altiplano soils under high altitude environmental conditions, nitrogen takes more than 50 days before it becomes available to the crop, and that in the first 25 days the nitrogen availability reduces and uses soil water, depleting crop yields. Therefore, if manure is to be added as a fertilizer for quinoa production, it should be done around two months before sowing or with a previous treatment to accelerate decomposition.

The second conclusion was that mineralization could be accelerated and the nitrogen efficiency improved if a previous treatment is applied to the fresh manure, either in compost pools or at least by covering the manure with plastic sheets and adding water to increase humidity, around 30 days before sowing.

The nitrogen needs for quinoa were also quantified. In this regard, different manure application rates were evaluated and compared in several locations in the central and southern Altiplano. The best application rate was found to be between 15 and 20 tonnes of manure per hectare, for which an average yield of 2,000 kg/ha of quinoa can be expected, if the minimal soil water content is assured.

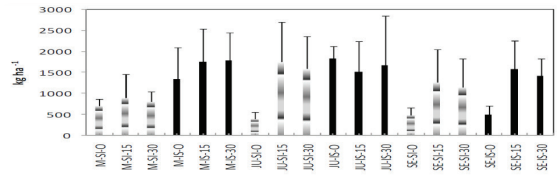


Figure 7.
Different timings for manure applications and yields. (M= May; JU=July; SE= September; SI= No irrigation; IS= Irrigated; 0, 15, 30= Manure application levels) (from Miranda, 2012).

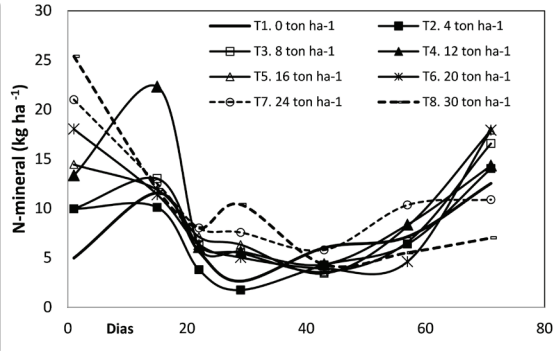


Figure 8.
Nitrogen mineralization rates of different application levels (from Miranda, 2012).

Finally, a quick inventory of manure availability for the main production areas was carried out, which showed that manure is becoming less available and more expensive for farmers. There are two main reasons for this: i) growing numbers of quinoa producers are demanding more manure (crop is mainly organic), and ii) more fields previously used for cattle and animal husbandry are now growing quinoa. Hence, it is very difficult at the farmer level to achieve the above mentioned guidelines on soil fertility management for quinoa production related to organic manure. The team therefore decided to compost organic household waste in order to provide

a solution in the future to the problem of reduced manure availability. Although not entirely completed, the composting tests are showing very promising results, with this method potentially becoming an alternative for organic quinoa fertilization.

3.3 Economy and market

Evaluations were developed of the social environment surrounding quinoa production and farming systems, especially in relation to the willingness among farmers to invest in the application of fertilizer and deficit irrigation. Results show that farmers would be willing to change their production systems if the government improved market processes and helped to protect crops against additional factors such as pests and disease. Moreover, it was clear that market pressure might play a more important role than climate in generating change in the dynamics of production. Conversely, erosion, desertification or climate risks do not play an important role in farmers' decisions if the principle driver is the market price of quinoa. Policies should therefore be oriented more towards filling the gaps between potential and actual field production in a sustainable manner and to strengthen market relationships.

It was also clear that external inputs for quinoa production could be better adopted by farmers owning larger fields from where they can obtain surplus production, and where there is already some type of irrigation. Social factors and age should also be considered, as young people are more willing to adopt new technology, as well as people who have a higher level of education.

The perceived climatic risks – the threat each hazard represents to their livelihood – are not as high as one would expect as farmers are heedful of climate crisis. Although the risk of frost, flooding and hail is perceived to be high in the Altiplano, production crisis related to pests, diseases and erosion are more prevalent and are perceived as major threats, consistent with increased warming and monocropping trends.

Finally, it can also be concluded that market chains are not well developed for quinoa, and that much of the production is lost through smuggling and the black market owing to the weak links used by smugglers to pay low fees to farmers, since they generally do not have other options for commercialization. Benefits are also largely lost in the intermediate chain. The government is therefore being called upon to improve these conditions.

4. Recommendations for sustainable dryland management

The expanded growth of quinoa production represents a great opportunity for improving the livelihoods of the Bolivian population, if the potentially serious threat to the environment is resolved and better marketing is ensured. High prices and worldwide demand have put pressure on the production system, and this pressure has encouraged poor environmental practices and some negative social and economic relations.

The crop has been cultivated in the Andean region for over 5,000 years, reflecting its historical and even cultural importance for the local population. However, the importance of the crop diminished in the last two centuries and was almost completely out of production, having been replaced by cereals such as barley and wheat. From the 1990s, a variety of projects began to crop up to re-establish traditional quinoa production for export markets. Today, the crop remains a financial success for Bolivian Altiplano smallholders.

Although boosting farmers' incomes and awakening local interest, the escalating prices of quinoa have had an impact on the local dynamics. In addition to the several social and economic problems encountered in the production and consumption chain of quinoa, the main problem of the system is the growing imbalance between sustainability and production. Traditionally, quinoa fields covered only part of the fragile ecosystem, and cattle (mainly llamas) grazed on the rest. In other areas, quinoa was not widely cultivated and livestock activities supported quinoa's manure needs. Today, cattle is being sold to make way for quinoa cultivation, which is much more intensive than before, increasing the likelihood of a food and soil fertility crisis as the quinoa production areas expand. Soil fertility is very limited as manure becomes increasingly scarce and in several instances is not used at all. Food safety crises may also occur if farmers switch from agrobiodiversity and livestock production to quinoa monocropping, which would be compounded without proper soil and water management.

From previous results it is clear that quinoa production cannot be limited by policies, laws or international campaigns considering that it supports Bolivian development where no other crops could develop, but there are vulnerabilities to be addressed with regard to future productivity and the sustainability of production. The analysis shows that if the production and exports of quinoa in Bolivia are to be sustainable, the agricultural practices must be both ecologically friendly and socially accepted. Although the purpose of this research was not to completely analyse the quinoa production system, the close cooperation with farmers and producer organizations revealed that soil fertility and water management, along with climate change impacts, are very important issues that need to be addressed with strong support of the commercialization and education chains. In order to help maintain the sustainability of crop production, soil and water management should become a priority, as well as awareness of climate constraints.

Considering that the aim is to produce more quinoa grains with less water and under a good fertilization programme, the following global considerations should be taken into account.

4.1 Climate

- The low temperatures in the production areas lengthen the production cycle of the crop, which in many years starts before and goes beyond the rainy season. This increases the risks for crop failure or much reduced yields. Thus, crop (deficit) irrigation to move ahead and adjust crop harvesting to the local rainy season would reduce the likelihood of crop failure and should seriously be considered.
- Dry spells are of little concern in the initial stages, provided that seed settling has occurred. However, they should be avoided with some form of water input if occurring after anthesis. Small amounts of water in this period could make a big difference in yields.
- Working with an average thermal time of 1600 thermal units would provide excellent hints for soil and water management in different production areas, such as the new expansion zones.
- Local knowledge on climate should be more deeply analysed to obtain valuable experience and guidance for climate management of the production environment.

4.2 Soil water and fertility management

To ensure an adequate nutrient supply for crops, we must strive to maintain a good balance of nutrients in the soil. The loss of nutrients has to be minimized, while maximizing efficiency in the addition of nutrients in order to prevent nutrient depletion in the soil. The removal of nutrients during the harvest

is unavoidable. The higher the yield, the greater the depletion of nutrients. Therefore, to increase quinoa yields in a sustainable way, it is extremely important to consider fertilizers, particularly as quinoa is well known for the high quality of its proteins, suggesting a strong nitrogen demand from the soil. Without fertilizers, there will be permanent nitrogen and nutrient depletion from the already poor soils, rapidly degrading the soil characteristics. However, the application of fertilizers (especially manure) at inappropriate times and quantities will not necessarily produce beneficial soil characteristics, and may even have a counter-productive effect on the soils, especially over the short term. Overly small quantities of incorporated manure within the production systems will result in increased field labour even though the effects on yields will not be significant. With such results, farmers get quickly discouraged and neglect to apply manure.

To be significantly effective, the application rates of manure should be high, up to 20 to 30 tonnes/ha, which will guarantee adequate revenue from crop harvesting and commercialization, and will help in maintaining a well developed soil structure. It is also important to remember that an adequate soil and water balance, as well as water availability during critical periods, is essential to see benefits from soil fertilization, especially manure application.

The timing of fertilization is also important when working solely with organic fertilizers. Manure application during sowing derives only limited benefits on crop yields because the nitrogen will only be liberated approximately 50 to 60 days *after* application. The best application timing is around two months prior to sowing, producing an adequate ageing of manure. An alternative is to work with compost, either for the accelerated ageing of manure or for transforming domestic or crop residues into available nutrients for quinoa. Given the decreasing availability of manure, strategic agreements with urban centres for the collection of domestic organic residues for composting is an alternative that should be strongly explored.

Last but not least, the team proposes to look at alternatives to organic fertilization. Since manure is unlikely to be widely available, other sources such as mineral fertilization could be explored, which could be an option for local markets that are less strict with organic production standards.

5. Research institution and team composition

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Eng. Sylvia Aliaga Zeballos

Graduate student and later field technician
Alex Borda

Graduate students
Pablo Mamani Ramos
Wilson Mercado
Gavi Alavi
Bersenia Salluco
Henry Mendoza
William Maceda

6. Publications as a result of SUMAMAD

Several academic and non-academic publications were made possible thanks to SUMAMAD support. The academic publications are mainly related to graduate and doctoral thesis. Non-academic publications refer to manuals or technical handbooks.

Graduate thesis and authors who received scholarships and field support funding from SUMAMAD for their research include the following:

No.	Name	Title Bachelor research
1	Bersenia Salluco	Fermentación del estiércol de llama (*Lama glama*), bajo dos condiciones de manejo (Municipio de Patacamaya Provincia Aroma Departamento de La Paz)
2	Pablo Mamani Ramos	Exportación y balance de nitrógeno en el cultivo de quinua (*Chenopodium quinoa* Willd.) bajo diferentes niveles de abono con riego deficitario en el municipio de Santiago de Callapa
3	Alex Borda	Evaluación del desarrollo y rendimiento de tres variedades de quinua (*Chenopodium quinoa* Willd.) con la aplicación del riego deficitario en el Municipio Santiago de Callapa – La Paz
4	Gaby Alavi	Mineralización de nitrógeno y carbono en el suelo de diferentes niveles de estiércol de ovino bajo condiciones de laboratorio
5	Sylvia Aliaga Zeballos	Evaluación del comportamiento del nitrógeno bajo diferentes niveles de abonamiento orgánico y riego deficitario en el cultivo de quinua (*Chenopodium quinoa* Willd)
6	Henry Mendoza	Productividad de quinua (*Chenopodium quinoa* Willd) bajo los efectos de niveles de estiércol ovino y condiciones de riego deficitario en el Campus Universitario Patacamaya
7	Wilson Mercado	Incorporación de niveles de estiércol fermentado y urea en el cultivo de la quinua (*Chenopodium quinoa* Willd.) bajo condiciones de riego deficitario en la Estación Experimental de Choquenaira
8	William Maceda	Efecto de compost y estiércol de ovino en el cultivo de quinoa (*Chenopodium quinoa* Willd.) – Villa Patarani Altiplano Central.

Doctoral researchers who received field support funding from SUMAMAD for their research:

Name	Title PhD research	Scholarship	Graduated
Cristal Taboada	Evaluation of the socioeconomic feasibility of deficit irrigation and fertilization in quinoa production systems of the Bolivian Altiplano	BTC + McKnight	K.U.Leuven (expected in 2013)
Jorge Cusicanqui	Scenarios for deficit irrigation for quinoa farming systems in the Bolivian Altiplano	BTC	K.U.Leuven (expected in 2013)
Roberto Miranda	Organic matter requirements for the sustainable production of quinoa in the central and southern Bolivian Altiplano	VLIR OI Quinagua project	Universidad Federal Santa Maria, Brazil (concluded)

Figure 9.
Quinoa research fields for Pablo Mamani's undergraduate thesis. © UMSA-SUMAMAD team

7. List of national seminars

2009. Intensive Workshop on Agroclimatology and Related Scientific Tools, 9–14 November 2009 in La Paz, Bolivia.

2010. First Bolivian Congress on Irrigation, 12–14 July 2010 in La Paz, Bolivia.

2011. National Course on Soil Microbiology and Fertility, 25–26 March 2011in La Paz, Bolivia.

2102. Bolivian Colloquium on Quinoa Sustainability, 25–26 April 2013 in La Paz, Bolivia.

8. References

Bradley, R. S., Vuille, M., Diaz, H. F. Vergara, W. 2006. Threats to water supplies in the tropical Andes. *Science*, Vol. 312, No. 5781 pp. 755–1756.

Blog de quinua. http://laquinua.blogspot.com/ Todo sobre la quinua. Capturado en Marzo de 2013.

Choquecallata, J. 1994. *Evapotranspiración máxima (ETM) del cultivo de la quinua por lisimetria y su relación con la evapotranspiración potencial en el altiplano Boliviano*. Tesis de Grado. Universidad Técnica de Oruro.

Cossio, J. 2008. Agricultura de conservación con un enfoque de manejo sostenible en el Altiplano sur. *Revista Habitat,* Vol. 75, pp. 44–49.

Garcia, M., Yucra, E., Michel, T., Callisaya, A. 2011. Atlas Agroclimático del Altiplano Boliviano. Facultad de agronomía UMSA.

Garcia, M., Raes, D., Jacobsen, S.-E., Michel, T. 2007. Agroclimatic constraints for rainfed agriculture in the Bolivian Altiplano. *Journal of Arid Environments*, Vol. 71, No.1, pp. 109–121.

Jacobsen, S.-E., 2011. The Situation for Quinoa and its Production in Southern Bolivia: From Economic Success to Environmental Disaster.

Geerts, S., Raes, D., Garcia, M., Del Castillo, C., Buytaert, W. 2006. Agroclimatic suitability mapping for crop production in the Bolivian Altiplano: A case study for quinoa. *Agricultural and Forest Meteorology,* Vol. 139, issue 3-4 October 12,pp.399–412.

Geerts, S., Raes, D., Garcia, M., Vacher, J., Mamani, R., Mendoza, J., Huanca, R., Morales, B., Miranda, R., Cusicanqui, J., Taboada, C., 2008. Introducing deficit irrigation to stabilize yields of quinoa *(Chenopodium quinoa Willd.)*. *Eur. J. Agron*. Vol. 28, pp. 427–436.

Miranda, R. 2012. *Organic matter requirements for a sustainable production of quinoa in the Central and Southern Bolivian Altiplano*. Doctoral research. Universidad Federal de Santa Maria, Brazil.

Quispe, R., Gilles, J., García, M., Yucra, E., Yana, G. 2013. Factores de pérdida de los conocimientos sobre el uso de los indicadores locales en comunidades del Altiplano norte y central. In: *Cambio Climático en el altiplano*. Revista CIDES-UMSA. La Paz, Bolivia.

Soraide, D. 2008. Comercialización de la quinua Real producida en el altiplano sur de Bolivia. Reporte FAUTAPO, p. 12.

Valdivia, C., Seth, A., Gilles, J., García, M., Jiménez, E., Cusicanqui, J., Navia, F., Yucra, E. 2010. Adapting to Climate Change in Andean Ecosystems: Landscapes, Capitals, and Perceptions Shaping Rural Livelihood Strategies and Linking Knowledge Systems. *Annals of the Association of American Geographers*. Special Issue on Climate Change, Vol. 100, No. 40, pp. 1-17

Valdivia, C. 2004. Andean Livelihoods and the Livestock Portfolio. *Culture and Agriculture*, Vol. 26, pp. 19–29.

Annex

Non-academic publications

1. Quinoa crop calendar

With Deficit Irrigation guidelines, manure timing applications, and thermal time required.

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2. Climate local indicators calendar

This calendar presents the biological and astronomical indicators of every month of the agricultural year (August–July) used by farmers i) to plan their cropping calendar, and ii) to warn them of imminent climatic constraints (local early warning system).

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3. Agroclimatic Atlas of the Bolivian Altiplano

The atlas presents the results of several years of climatic research in the Altiplano, giving a description of the thermal and rainfall characteristics and aptitude of the area for general cultivation, particularly quinoa.

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4. Compendium of our research

Scientific contributions of the major findings of the Masters and PhD research conducted in the framework of the SUMAMAD project presented in different chapters.

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Mare aux Hippopotames Biosphere Reserve

By Jean-Noël Poda, Mamounata Belem/Ouedraogo and Ollo Théophile Dibloni

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Burkina Faso

Executive Summary

With a Gross Domestic Product estimated at US$240 per capita (1997) and an economy based on agriculture and breeding, Burkina Faso, a Sahelian and landlocked West African country, is one of the poorest nations in the world with a very high incidence (45 per cent) of general poverty (INSD, 2000). The concentration of 'environment refugees' in the best zones in the south led Burkina Faso to first experiment with the biosphere reserve concept in the Mare aux Hippopotames forest reserve, which became a biosphere reserve in 1987 and a site of sustainable development and the observation of climate change indicators (Poda, 1990).

To alleviate poverty and as a survival alternative, the village populations around the biosphere reserve depend on income diversification with additional resources obtained from vegetation and wildlife. The resulting biodiversity loss has increased alarmingly and efforts to reverse the current trend of degradation are limited owing to a lack of financial support, scientific capacities, as well as inadequate alternative resources to reduce the pressure of the escalating population (Poda et *al.,* 2012).

These constraints prompted Burkina Faso to seize the opportunity presented by UNESCO's Sustainable Management of Marginal Drylands (SUMAMAD) project to resolve one of the most urgent problems facing dryland countries: how to reconcile the conservation of ecosystems and biological resources with their sustainable use in the context of increasing poverty.

1. Introduction

The biosphere reserve is located between the latitudes 11°30' and 11°45' North and longitude 04°05'and 04°12' West (Fig. 1 and Fig. 2). The climate is of the Sudanian type with an average annual rainfall of 800 mm. The deterioration of the climatic conditions has been observed for many years and the limits of some isotherms have moved more than 50 km further south (Bonkoungou, 1985). This climatic shift has led to more migrations, resulting in significant anthropic pressure around the biosphere reserve. The combined effects of the deterioration of the climatic conditions and land mismanagement (extensive agriculture, fallow time reduction, overgrazing, bush fires, and so on) not only cause serious problems of desertification, but also general underdevelopment and increasing poverty.

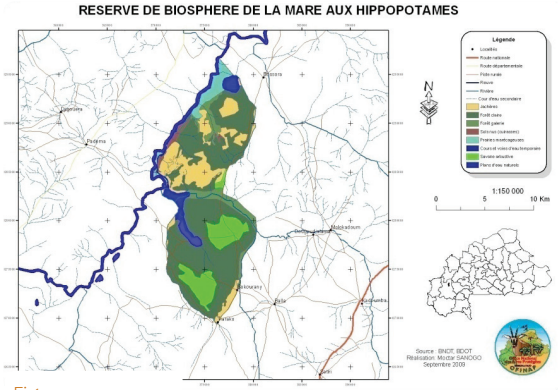

Figure 1.
Geographic location of Mare aux Hippopotames Biosphere Reserve, Burkina Faso. © Burkina Faso MAB Committee

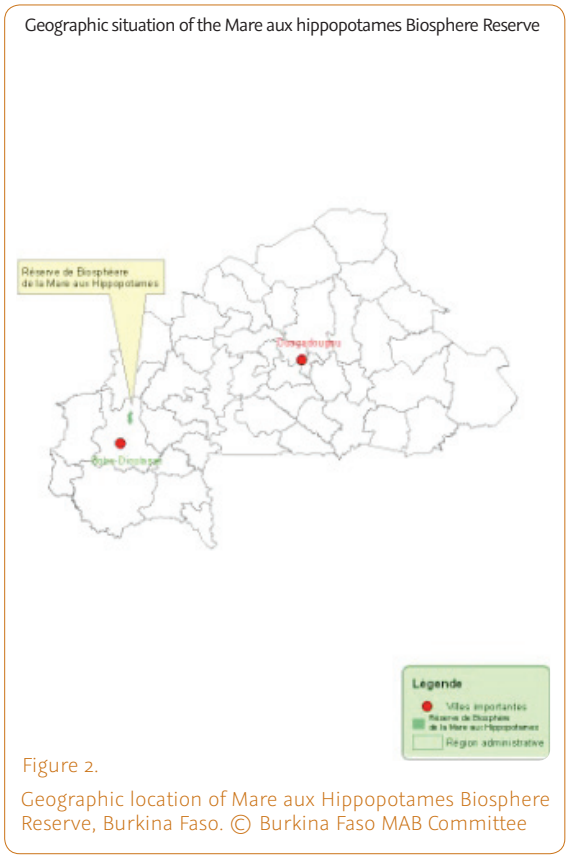

Figure 2.
Geographic location of Mare aux Hippopotames Biosphere Reserve, Burkina Faso. © Burkina Faso MAB Committee

Sustainable resources management now seems to be a mobilizing factor in understanding the various environmental management stakes facing dryland countries. At the local level, as well as in all dryland countries, it now seems possible to discuss the challenge relating to the management of biosphere reserves from the angle of sustainable development. The shared experiences among dryland countries in the framework of SUMAMAD, with regard to conservation and the sustainable use of resources, might together contribute towards finding approaches in the use and rational exploitation of natural resources for future generations (Poda et *al,* 2012). These adapted responses will generate benefits, while ensuring a balanced approach to management and the conservation of ecosystems and biological diversity in every participating country.

With the objectives of the SUMAMAD approach identified (in workshops held in Syria 2006 and China 2007), the Mare aux Hippopotames Biosphere Reserve (MHBR) can be considered a model for all stakeholders in Burkina Faso in safeguarding natural resources, while participating in the country's development.

2. Objectives and activities of the SUMAMAD project

The need for development and research highlights the concerns of the various stakeholders (producers, farmers, state departments, NGOs, development projects and programmes).

The objectives of the SUMAMAD project are well integrated into the general objective of inscription of the biosphere reserve in the International Network of Biosphere Reserves as defined in 1987. Given the fact that the process of achieving this objective can take several years, three main specific objectives were defined in terms of activities and expected outputs over a four-year phase. These activities must bring about social innovation and experimentation of participatory methods that enable populations to sustainably manage resources and thus control poverty.

Specific objective 1: Given the agricultural pressure exerted on local populations and 'environment refugees', it is vital to carry out objective 1 based on scientific studies on land management surrounding the Mare aux Hippopotames biosphere reserve through:

- an evaluation of agricultural lands and utilization practices, including local knowledge around the MHBR to halt or reduce land degradation;

- the establishment of pilot and demonstrative sites of orchards with introduced plants, and agroforestry with local plants.

Specific objective 2: Considering the impact of climate change, the interactions within the ecosystems, and the perception of these phenomena by the populations bordering the MHBR involves:

- the documentation of different scenarios of anthropological change (agrarian and land reforms) and natural phenomena (climate change);

- the formulation of a sustainable management plan, which takes into consideration forest protection and the agro-sylvo-pastoral lands of villages bordering the MHBR;

- the adoption of pedagogic tools for countries located in dryland zones (a creative approach to environmental education) in the two rural communities bordering the MHBR.

Specific objective 3: From the implementation of objectives 1 and 2, the local populations would require alternative production activities through the promotion and diversification of income-generating activities to stem poverty and to reduce actions that degrade the natural resources (ecotourism, fishing, handcraft, honey production, wood exploitation, medicinal and alimentary plants exploitation).

3. SUMAMAD project implementation

From the moment UNESCO funding was announced, an information and organization session was planned by the MAB focal point. Participants included managers from the Centre national pour la recherche scientifique et technologique (CNRST),[1] the UNESCO National Committee, the universities of Ouagadougou and Bobo-Dioulasso, agricultural workers, livestock producers, and environmental, educational and NGO field workers. With the assistance of co-funding through the SUMAMAD project, various offers of support were reasserted. Synergy with ongoing actions in the area was strongly promoted, characterized by the need for consultation and solidarity.

The MAB Committee is composed of researchers from the universities of Ouagadougou and Bobo-Dioulasso and from CNRST. As a result of the multiplicity of subjects and competences of field technical agents from the State and NGOs, the distribution of tasks and activities were carried out during the wait for the transfer of funds.

3.1 Improved dryland agriculture and rehabilitation of degraded areas

Faced with the growing challenges posed by nature, the population has for a long time chosen traditional strategies of water and soil conservation in order to support the sustainable use of natural resources (Bonkoungou, 1985; Poda et *al.,* 2012). In searching

1 Centre National de la Recherche Scientifique et Technologique. Ministry exclusively in charge of higher education, scientific research and universities.

to improve living standards, as well as adapting to the process of desertification with the associated climatic hazards, it was important for the SUMAMAD team to document the development of arable lands by the population. These experiments were drawn from daily life during the years. The endogenous experiments were enriched in 2012 within the framework of the trainees' activities and whose documentation referred to:

- water economy and its optimization for plants (case of dry season crops);
- combating erosion and soil protection (case of protecting valves with stone, plants or both);
- adaptation of farming methods (case of agroforestry, top slope weeding, organic manure); and
- adoption of agricultural innovations (improved seeds, including short cycle, and crop diversification).

The agro-sylvo-pastoral production needs are very relevant, whereas the natural resources do not offer high capacities for their exploitation (Fig. 3).

Figure 3.
Stony cordons in agroforestery. © Burkina Faso MAB Committee

3.2 Resumption of the ecological orchard initiative and joint visits

In agreement with agricultural producers from the transition zone area, the trainees decided to plant ecological orchards; setting up agroforestry pilot farms with fruit bearing trees improved through research. These ecological orchards are agroforestry demonstration sites comprising fruit trees. The success of these orchards justifies the reproduction of these experiments in the villages. The first crop of cashew nuts was expected for 2010, and should provide financial added value for the landowners, while helping to reduce the impact of cotton crops using fertilizers and pesticides with their adverse impacts on biodiversity and ecosystems. Unfortunately, owing to the lack of communication regarding land ownership, an important part of the orchards was destroyed. In 2011, an in-depth investigation was undertaken to address the problems and propose solutions with the objective of planting agricultural farms in areas where this activity is practised. In the long run, agroforestry farms will provide alternative incomes to farmers and be used as an example of generalized agroforestry farms to replace the cotton farms around the biosphere reserve.

In addition, the SUMAMAD project allowed populations from several villages to tackle the problems identified:

- Cutting trees for cultivation results in soil erosion under the effects of streaming rain.
- Silting and covering the pond with sand threaten fishing and biodiversity survival.
- The abundant use of chemical fertilizers and pesticides in fields contribute, through the washing phenomenon, towards water pollution.
- The importance of herbaceous and pastures areas in the biosphere reserve.

A study undertaken by SUMAMAD researcher Sébastien Kiema demonstrated that it was possible and even profitable for villagers to graze their herds in the forests to reduce herb quantity, which is dangerous in the case of bush fires. A follow-up on research on grazing and pastures showed that increased grazing led to less bush fires and the regeneration of useful species (*Parkia biglobosa* and *Vitellaria paradoxa*), as well as an increase in their fruit productivity.

3.3 Pollinating insects and impact of agricultural pesticides

The SUMAMAD project focused on insect diversity in connection with the spreading of pesticides by farmers, mainly by cotton producers. The trainee showed that the majority of the indexed insects belonged to the orders of Hymenoptera, Diptera, Coleoptera, Hemiptera and Lepidoptera. However, the partial data did not make it possible to describe their distribution according to the area's anthropophilic level. Moreover, some observations showed that not all insects are effective pollen conveyors, even though effective pollination has strong consequences on the reproduction of the flowering plants, including food crops and medicinal plants.

Through the work carried out by students and trainees, the aim is to evaluate the pollinating potentials in various agro-sylvo-pastoral areas of Farakoba, Dindérésso and Bala. The working hypothesis is that *human activities influence the specific diversity of insects and more particularly the pollinators*. To check the hypothesis, it is necessary to answer two questions:

- What is the impact of the anthropophilic area (anthropisation) on the specific diversity of pollinating insects?
- Will forests (old fallows) be 'source zones' from where the insects disseminate?

Collections in the various defined areas show an unequal distribution of utilitarian insects with the most significant collections conducted in old fallows. At Bala (bordering village of the biosphere reserve) the fallows located close to cotton fields (or former cotton fields) revealed that some families are not represented in these zones, which supposed a link with pesticide use, though this assumption requires better data documentation. Apidae, Nymphalidae, Muscidae, Sepsidae and Syrphidae seem more broad-based and are present in variable numbers depending on how long the fallow has been in existence. In fallow land on plateaux, where cotton farming is low, collections show the significant presence of visiting insects of Apidae, Megachillidae and Anthophoridae families.

3.4 Lessons learned

The lessons learned from contact with the populations and their practices indicate that poverty is linked to the recurring droughts and is accentuated by environmental pollution. This situation will only worsen and is the reason why the documentation of good endogenous practices as alternatives of adaptation and crop improvement in rural areas contributes towards the SUMAMAD project and the achievement of one of the Millennium Development Goals (MDGs): to halve the proportion of people with incomes less than US$1 per day.

These experiments have been included in a relevant valorization document of the Ministry of Technology, Scientific Research and Innovation.

4. Scenarios for future land-use changes

Surveys on the protected areas reveal that bush fires and exploitive wood cutting constitute the main causes of degradation of vegetation; breeding and agriculture rank third and fourth, respectively. This tendency may reverse with the strong development of agricultural solutions (Poda, 1990). The combined decentralized management of forests and soils, incorporating the biosphere reserve and the zoning management plan, can be applied as a model in the sustainable exploitation of natural resources in the context of sustainable local development and poverty mitigation. This process also acts an indicator, as recommended by the Strategy for Accelerated Growth and Sustainable Development (SCADD).

4.1 Climate change

4.1.1 Climate change, food security and health

The decrease in vegetation and animal production prevents the population from obtaining access to sufficient and healthy food to meet their basic nutrition needs. Thus, the biosphere reserve area is always in surplus production, with many households that were previously self-sufficient falling into temporary food insecurity (Poda et *al.*, 2012). The SUMAMAD data shows that unpredictable rainfall affects cereal production and pasture with serious foreseeable consequences that include increases in food vulnerability, chronic disease and malnutrition. This ultimately leads to a pronounced increase in growth disorders, suggesting that children do not develop adequately. Moreover, the spatial distribution of malaria and bacterial meningitis, which is linked to latitude and rainfall (the rainy season for malaria and the harmattan for meningitis), means that a longer dry season may reduce malarial impact but increase the persistence of meningitis.

4.1.2 Climate change: perceptions, adaptations

The populations on the ground are at the forefront of climate change impacts such that their adaptations over time have become survival strategies. The SUMAMAD research team collected real life experiences with a view to targeting the adaptations and behaviours related to each situation. At the populations level, climate change perceptions and indicators include violent storms, irregular rainfall patterns, disturbance in the duration of the various seasons in the year, a gap between sowing periods, the gradual disappearance of biodiversity, lower crop yields, modification of the fodder system characterized mainly by the disappearance of the most grazed plant species, noticeable changes in landscape physiognomy, and wildlife disappearance. At the social level, the local populations experience poverty and child malnutrition.

4.2 Environmental education

The SUMAMAD project contributed towards formalizing a partnership with four primary schools from four bordering villages, which included the public awareness programmes of the young schoolchildren living close to the Mare aux Hippopotames biosphere reserve. The activities have a strong awareness raising impact and are implemented through plays, essays, tales, ballets and sketches (Fig. 4).

The UNESCO Teaching Resource Kit for Dryland Countries was presented to education stakeholders of the biosphere reserve and served as a tool to develop a pedagogic approach with content to improve the curricula in non-formal and formal education in the biosphere reserve. Environmental education through theatre was also encouraged in SUMAMAD's research

themes. Training for stakeholders on climate change perceptions and indicators was proposed with the view to harmonizing educational approaches and content.

The 9th SUMAMAD workshop and the commemorative activities of the 40th anniversary of the Man and Biosphere Programme (MAB/UNESCO), held in 2011 in Bobo-Dioulasso, presented an outline of the activities carried out among the schools bordering the biosphere reserve.

Figure 4.
Pupils of Bala. © Burkina Faso MAB Committee

4.3 The structural framework: Inter-village association (AGEREF)

The biosphere reserve includes five riparian villages (Padema, Bossora, Tiérako, Sokourani and Bala), three of which (Tiérako, Sokourani, Bala) are strongly involved in fish farming. The 'Inter-village association of natural resources and fauna in the Hauts-Bassins' (AGEREF-HB), a local socio-professional organization that includes farmers, breeders, fishers, hunters, women, mutual aid associations, among others, acts as an intermediate for activities carried out by the producers within the SUMAMAD project, which ensures the sustainable and participative management of natural resources in the area. In the context of the biosphere reserve, the National Department of Protected Areas (OFINAP) permitted the creation of the inter-village association (AGEREF), which facilitates exchange with other institutions and acts as an interface for conducting SUMAMAD activities.

The students and trainees lived with the producers and applied the Accelerated Method of Participative Research (MARP) in the Mare aux Hippopotames biosphere reserve and the riparian villages. The following findings were observed:

- There are huge natural and agricultural potentials.
- The environment is changing due to strong migratory pressures.
- Production systems are evolving and natural resources are degrading.

The analysis of biodiversity indicates that:

- As a whole the forest ecosystems are well preserved.
- Many features of vegetation, especially in the forest galleries, provide real potential to ensure the preservation of biological diversity.
- Flora and fauna diversity, despite inventories taken during the 'Partnership for the Improvement of Natural Ecosystems Management' (PAGEN) project, requires follow-up to assess quantity and quality, and factors that regulate the different elements.
- Degradation tendencies are perceptible, despite efforts made by the actors involved (PNGT, OFINAP).

Three members from the fishermen's organization were trained in good practices as tourist guides. In September 2010 the president of AGEREF took part in

the International Tourism and Hotel Business Show of Ouagadougou (SITHO, 2010).

5. Ensuring sustainable livelihoods through alternative income-generating activities

To alleviate poverty and as a survival strategy, the population of the villages around the biosphere reserve depend on income diversification and the additional resources obtained from vegetation and wildlife. The resulting biodiversity loss has increased alarmingly and efforts to reverse the current trend of degradation are limited owing to a lack of financial support, scientific capacities, and inadequate alternative resources to reduce the pressure of the growing human population.

5.1 Biodiversity conservation and sustainable use of natural biotic resources: Non wood forest products (NWFP)

Income-generating activities such as non-wood forest products (NWFP), fishing, apiculture, and hippopotamus tourism are becoming increasingly important in the local economy.

Out of ten products presented as a priority in the biosphere reserve, the most favoured three species in the riparian villages are *Adansonia digitata, Parkia biglobosa* and *Vitellaria paradoxa* – the preferred agroforestry species identified by Belem (2008). According to Belem (from Guinko et *al,* 1992) the gathered products are well traded and generate important income for many families. Research carried out in 2009–12 showed an increased demand among the population for:

- the collection of dead wood in bushes not far from the village;
- the collection of leaves, barks and roots of various plants for medicinal use;
- the collection of macrophytic mushrooms for sauce preparation, the main activity of women during the rainy season; and
- traditional apiculture undertaken with traditional bee hives installed in trees.

All non-wood forest products are very intensely exploited. This situation is mainly due to the important role played by forest products in food security. Cattle feeding, housing, handicrafts, magic and religion are also sources of income. The various activities are initiated by stakeholders (women) who are well aware of the stakes regarding preservation and income-generation in terms of poverty alleviation. Moreover, stakeholders in the field require training in processing and preserving technologies.

5.2 Demonstration and training for producers on income-generating activities

The lack of medicine and food, and the high cost of drugs and modern ointments drive the population towards traditional healers and plant gathering. The population not only know the virtues and various uses of the plants, they also possess traditional food and medical knowledge. In addition, reports from the field reveal that medicinal and food plants exploited in each village fall within the framework of income-generating activities but are not inexhaustible resources. Plantations are therefore supported by the SUMAMAD project in the bordering villages of the biosphere reserve, and comprise food and medicinal

plants of mainly useful local species (mango tree, cashew tree, néré, tamarind, baobab, shea tree, and so on), which are used for food and pharmacopeia and are endangered around the villages. In addition to the preservation of biodiversity, these plantations make up the deficit in micronutrients and medicinal plants as regards food and medicine, as well as increasing income-generating opportunities.

These experiments are documented and are used as demonstration and training sites for producers. Faced with the multiple concerns of the populations and authorities, and to ensure the rational management of biodiversity, the results will be exploited for use in non-formal educations programmes. An important aspect of the SUMAMAD project is to contribute towards the improvement of living conditions among the communities. Consequently, recommendations were made during the local general assemblies of the population of the riparian villages.

5.3 Fish farming activities

The 52 species of ichthyo-fauna of the Mouhoun bassin (or Black Volta) is best known thanks to the work of Roman (1966). As for the hippopotamus pond, its fish fauna is known thanks to the work of Couteron *et al.*, (1989), Baijot *et al.*, (1994) and Sanon (1995). The fish species found and caught in the framework of SUMAMAD project are less than twenty, compared to between 28 and 42 fish species recorded by the former authors. The captured fish species were identified from the systematic description of Lévêque *et al.*, (1990*a*; 1990*b*).

The pond is exploited throughout the year by a community of fishers from the riparian villages of the biosphere reserve and sometimes from elsewhere. Because of the disparity in rainfall from one year to the next, the Mouhoun floods, and overfishing, fish stocks are at risk owing to limited resources and the poor exploitation methods used by the fishers.

The surveys of 2010 and 2011 compare with the previous studies of the project 'Fish management in the South-West' (GPSO) from 1988–1996, as well as the PAGEN project in 2005 and 2006. This survey measures the fishing effort (number of fishers, quantity of fishing equipment, fishing days) invested in the fish resources of the pond.

Various techniques were used to better control the impact of fishing on the ichthyo-fauna of the pond, which included three types of passive fishing equipment: gill nets (35 mm and more), fish traps and long-lines. The use of casting nets, the only active equipment, was limited to the dry season. The number of fishing days was estimated at between 110 to 130 days per year.

The Hippopotamus Pond is exploited primarily by fishers from the three riparian villages: Bala, Sokourani and Tiarako. Most fishers are fishing-farmers, which is to say that they practice fishing as a secondary activity. There are five fish families exploited for commercial interests. Other important food or economic species, representing 10 per cent of the catch, were occasionally caught. Among these were *Lates niloticus, Auchenoglanis occidentalis, Parachanna obscura* and *Labeo sp.*

Thanks to its favourable ecological and biological conditions, the pond is very productive with an estimated production of more than 40 tonnes of fish per year, equivalent to an annual yield of more than 300 kg/ha/year. The near total quantity of fresh catches are collected and sold by traders from Bobo Dioulasso. The purchase price of one kilogram of fresh fish sold by fishers varies on the size of the species, or the prestige of fish such as those called 'captain and horse'. Prices rose in 2010–2011 compared to those practiced five or fifteen years ago.

It can be concluded from the collected data that fishing on the pond and the adjacent Mouhoun River plays an increasingly important part in the household budget of the riparian villages. Though a renewable resource, fish – like all other natural resources – is fragile, particularly because of lake eutrophication due to the increasing quantities of pesticides and chemicals used in agriculture. The involvement of AGEREF is necessary for the sustainable management of resources, while OFINAP carries out the monitoring of fishing activities. Despite the pond's high productivity, fish resources are threatened by the tendency towards exploitation with a large amount of fishing equipment used on the water compared to production levels. For example, the number of gill nets is six times higher than normal in the context of rational resource exploitation.

The implementation of a previous recommendation on the monitoring of fishing and catches helped to better assess the evolution of fishing efforts and pond production levels. In this regard, a survey was conducted in 2009–2013 to monitor the number of fishers and the quantity of equipment used. The system of data collection on fishing put in place by OFINAP should also be reinforced in order to monitor catch levels.

6. Results obtained

The fauna of the Mare aux Hippopotames Biosphere Reserve is famous for its hippopotamus (*Hippopotamus amphibius* L.) that are permanent residents, giving their name to the biosphere reserve (Fig. 5). Other mammals, birds and fish are also found, with the large fauna and fish the subject of study in previous years, but not ornithology. Continued collaboration with ongoing studies at *Samandéni* dam in the upstream of the Mare aux Hippopotames Biosphere Reserve enables the study of i) aspects of flora biodiversity, ii) aspects of fauna biodiversity, and iii) the impact of high agricultural pressure, especially from cotton farming and the use of manures and pesticides on entomological fauna.

Figure 5.
Herd of hippopotamus
© O.T Dibloni/Burkina Faso MAB Committee

6.1 Fostering scientific drylands research: flora biodiversity

The inventory on the forest galleries reveals 270 species of flora, comprising 198 genus and 70 families. Out of 70 families, only 10 belong to the monocotyledon class with 37 genera and 51 species, and 60 families of dicotyledons of which Leguminosae make the most important group with 3 families. The ratio number of genera to number of species is 1 at the forest galleries of the biosphere reserve, whereas it varies from 0.5 and 1 in other places.

The results on the vegetation reveal that in the biosphere reserve galleries have a high percentage of Guineo-Congolian flora, around 61.7% to 38.3% of Sudano-Zambezi type, contrary to findings by Sall *et al.* (1997), quoting Guinko, who found in the savannah about 2.1% of Guineo-Congolian and 62.4% of Sudano-Zambezi. The high percentage of Guineo-Congolian

flora shows that the galleries of the hippopotamus pond have several floristic similarities with the Guineo-Congolian forest type, said to comprise a relict of woody forest in the past.

The aquatic vegetation of the pond – one of the particularities of the reserve – was especially documented in which 106 taxum were inventoried, including 15% hydrophytic vegetation, 44% of helophytes, 20% opportunistic hydrophytic vegetation, and 24% transgressive hydrophytic vegetation. This flora includes 34 families with 68.4% dicotyledons, 18.4% monocotyledons, 10.5% pteridophytes and bryophytes. The analysis of the elements and phytogeographic groups highlight the category of plants with large distribution such that 40.3% of the species found are from tropical Africa, 23.5% are pan-tropical, 12.2% are paleo-tropical and 5.6% Afro-Asian and cosmopolitan (Sall *et al.,* 1997). These data show that the water ways are upstream of Guinean flora in the Sudan region. Those various chorological characteristics clearly underline the originality of this flora, which has adapted to areas with very particular conditions.

6.2 Fostering scientific drylands research: fauna biodiversity

6.2.1 Animal biodiversity: wild mammals

The surveys conducted in the biosphere reserve reveal that there are 35 wildlife species in the biosphere reserve, including 28 that are known by more than half the population. Species were identified through direct observation and presence indicators (droppings, tracks, holes, and impact on vegetation) during the various inventories conducted (Dibloni, 2011). Important mammals include hippotragus, bushbuck, wart hog, elephant, cephalophus and oribi, which for the most part are observable through their presence indicators. Some of these species are highly regressing today, especially kob (*Kobus kob),* waterbuck (*Kobus ellipsiprymnus)* reedbuck (*redunca sp.*), and bubal antelope (*Alcelaphus buselaphus buselaphus*). The introduction of corridors between the different reserved areas in the region for the big fauna, namely the reserved forest of Maro and that of Téré, might secure and render their habitat viable.

6.2.2 Animal biodiversity: birds

The hippopotamus pond of the biosphere reserve, sheltering several bird species is a Ramsar site. The list of birds observed over the period in the downstream of Samandéni dam along the Mouhoun River, and more particularly at the Mare aux Hippopotames Biosphere Reserve, confirms PAGEN inventories. Poussy and Bationo (1991) numbered 125 bird species distributed among 41 families, with the following being the most represented: 15 Accipitridae species, followed by Ardeidae and Ploceidae with 8 species each, Estrildidae and Columbidae with 7 species each, and Alcedinidae, Charadriidae and Sylviidae each with 6 species. During the SUMAMAD project, the inventories carried out across a very wide area along the Mouhoun from the site of Samandéni dam to the Mare aux Hippopotame Biosphere Reserve found 125 bird species distributed among 41 families. The most represented are Accipitridae with 15 species, followed by Ardeidae and Ploceidae with 8 species each, Estrildidae and Columbidae with 7 species each, then Alcedinidae, Charadiides and Sylviidae each with 6 species. The pond and forest galleries abound in a rather appreciable avian potential.

7. Recommendations for sustainable dryland management

The implementation of the SUMAMAD project in Burkina Faso aims at countering the combined effects of degraded climate conditions and poor land management (extensive agriculture, overgrazing, bushfires, and so on). In line with the spirit of the Man and Biosphere Programme, the SUMAMAD project raised awareness on high soil exploitation (cotton production) and pressures on other resources that might create a particularly worrying situation of resource/population imbalance.

7.1 Impact of SUMAMAD activities

The SUMAMAD activities carried out in partnership with OFINAP, PNGT, together with the scientific and technical support of training and research organizations (CAP/Matourkou, ENEF, Dindéresso, IDR/UPB, and CNRST) will be reinforced around sustainable management, natural forests, ecological orchards, and the fight for anti-erosion associated producers.

Faced with the multiple concerns of the population and authorities, and to ensure a rational management of biodiversity, the results will be extrapolated for use in formal and non-formal educations programmes. It is an aspect of the sustainability of the SUMAMAD project that it modestly contributes towards improving the living conditions of the communities. Recommendations were therefore made in this regard during the international workshops of the SUMAMAD project.

Through the SUMAMAD project activities, AGEREF aims to identify and implement synergies between cotton production, agricultural, pastoral and fish farming, as well as the sustainable conservation of natural resources, while giving credibility to the following actors:

- Office National des Aires Protégées (National Office of Protected Areas) – OFINAP;
- Société Burkinabè des Fibres Textiles (Burkinabe Society of Textile Fibres) – SOFITEX;
- Programme National de Gestion des Terroirs (National Programme of Land Management) – PNGT;
- Office Nationale du Tourisme Burkinabè (National Office of Tourism) – ONTB;
- Direction Régionale de l'Environnement et du Cadre de Vie (Regional Department of Environment and Quality of Life) – DRECV;
- Association inter villageoise de Gestion des Ressources Naturelles et de la Faune (Inter-village Association of Natural Resources and Fauna) – AGEREF; and
- other local services.

With regards to the impact of activities carried out, the people whose behaviour significantly changed were often those who had received training and awareness-raising orientation in the context of the SUMAMAD project, or in partnership with other structures and projects. Such activities helped them understand indicators and the importance of sustainable management of natural resources.

7.2 Impact of national seminars

The national seminars recommend: i) to include the SUMAMAD project in the planned annual activities in the Mare aux Hippopatames Biosphere Reserve; ii) to involve stakeholders who had provided finance and/or co-founded the planned activities, taking

into account the delay before activities take place; iii) to test the participative and co-construction approach with AGEREF in helping carry out activities, especially land use practices, including local know-how, as well as experimental demonstration sites for local initiatives; iv) to plan the implementation activities in connection with poverty alleviation that satisfies basic needs, with soil restoration through agroforestry and organic manure, with better cattle breeding system by growing fodder plants in transition zones with apex associations (AGEREF), and v) to converge with other projects and programmes implemented in the area, which would help co-fund the planned activities.

The training activities carried out in 2009 and 2010 during the national workshop had positive impacts. An evaluation was undertaken in 2011 with the partners GGF (Groupement de Gestion Forestière) and AGEREF.

The people whose behaviour significantly changed had participated in organized structures such as GGF, fisher groups and AGEREF. They have for the most part received training and awareness-raising, which helped them understand the indicators and the reality of sustainably managing natural resources.

The case of the AGEREF group is particularly notable in the general tendency towards using sustainable techniques to control natural resources exploitation (soils, water and vegetation). Impact is noticeable through the stabilization of unfavourable indicators. The next step should be changes in behaviour.

7.3 Lessons learned

The appropriation of the SUMAMAD project in terms of conception and implementation was translated into: i) the adoption of the annual and five-year planning; ii) responsibilities given to stakeholders in the implementation of the planned activities and training for farmers; iii) consultation and synergy of ongoing projects and programmes in the zone for possible co-financing of some activities:

- The participative and co-construction approach should be taken more into consideration, especially land use practices, including local know-how, and ii) the experimental sites for demonstration for local initiatives (management of soil fertility, ecotourism, medicinal plants, hunting by villagers, fishing, handicrafts, forest non-woody products, firewood and timber).

- The implementation of consensus activities are connected to poverty alleviation and satisfying basic needs through i) soil restoration through agroforestry and organic manure, and ii) the introduction of a better cattle breeding system by growing fodder plants in transition zones with apex associations (AGEREF).

- Environmental education was regarded as the basis of sustainability for the undertaken actions. The UNESCO environmental education kit could use the range of media supports for each target group, including chiefs and customs guardians.

- Data from the MAB Committee website, visits to other sites, and the dissemination of research results increase the visibility of actions and serves as an interface with decision-makers, technical partners, and other national and international programmes and projects.

7.3.1 Challenges

- The multiplicity and diversity of needs expressed by the populations bordering the biosphere reserve and the populations of the other demonstration sites.

- Contradictory approaches (case of high cotton productivity with the intense use of pesticides and insecticides, and our approaches of sustainable development with a better conservation of natural resources).

- The site of the biosphere reserve being so remote from the pilot sites (Bougouriba, Comoé, Oubritenga and Yatenga provinces).

- The high request for internships and training (technicians, Masters) of IDR/UPB, ENEF/Dinderesso, CAP/Matourkou with limited resources.

7.3.2 Suggested solutions

Hints of solutions include using the MAB committee to interface the SUMAMAD project with ongoing projects and programmes being carried in the demonstration sites. We empower local players, especially technicians of engineering departments from the studies sites.

8. Research institution and team composition

Partner institution
Ministry of Scientific Research and Innovation (MRSI)
National Centre of Scientific and Technological Research (CNRST), MAB/CNRST B.P. 7047, Ouagadougou

Team Leader
Jean Noël Poda
Director of Research
Focal point of MAB Burkina Faso, Project leader

Deputy team leader
Théophile Ollo Dibloni
Fauna Researcher
DPF/INERA/CNRST

Project team members
Mamounata Belem Ouedraogo
Botanist researcher
DPF/INERA/CNRST

Paulette Taita
Botanist researcher
DPF/INERA/CNRST

Dayéri Dianou
Microbiology researcher
IRSS/CNRST

Désiré N. Coulibaly
Veterinary, fish biologist
DPF/INERA/CNRST

Ministry of Secondary and Higher Education (MESS)
University of Ouagadougou
Gustave Kabre
Biology Professor
UFR/SVT/UO responsible of training of young researcher

Polytechnical University of Bobo-Dioulasso (UPB) specializing in Technology
Mipo Hien
Professor of Agronomy
Institute of Rural Development, (IDR/UPB)

André Kabre
Professor, Researcher on Fishing and Fish farming (IDR/UPB)
Responsible for training young researchers.

Ministry of Environment and Sustainable Development (MEDD)
Amadé Ouedraogo
Junior Forestry Engineer
OFINAP

Lamoussa Hebie
Forestry Engineer

Alfred Millogo
Junior Forestry Engineer ex Partnership plan for a better Natural Ecosystems Management (PAGEN)

Other ministries
Local services of the Ministry of Agriculture and Food Security, the Ministry of Water, Hydraulic Infrastructure and Sanitation, and the Ministry of Animal and Fishery Resources.

Other members
Community organizations of the neighbouring villages.

Inter-village associations for Natural Resources and Wildlife Management (AGEREF).

Other organizations for training and research results enhancing, NGOs, technicians and other people whose contribution is necessary for the various expected outputs will work with the various teams.

9. List of national seminars

2009. The first national SUMAMAD seminar and hands-on training with partners took place 8 October 2009 in Bala village in the Mare aux Hippopotames Biosphere Reserve, Satiri department, Houet province.

2010. The national SUMAMAD seminar and hands-on training with partners took place 6 January 2011 in Bala village in the Mare aux Hippopotames Biosphere Reserve, following the SUMAMAD workshop in Alexandria, Egypt, in November 2010.

2011. The year marked the 40th anniversary of the Man and the Biosphere Programme (MAB/UNESCO). The national SUMAMAD seminar and hands-on training with partners took place 18 December 2011 in Bala village during the celebration of the 40th anniversary of the MAB/UNESCO programme, and the Ninth International Workshop of SUMAMAD Phase II in Bobo-Dioulasso, Burkina Faso.

2012. The national SUMAMAD seminar and the SUMAMAD local general assembly of the population of the riparian villages took place the 11 October 2012 in Bala village in the Mare aux Hippopotames Biosphere Reserve.

10. Publications as a result of SUMAMAD

Poda, J.N., Belem, M., Dibloni, O. 2009. *Desertification and adaptation of producers' endogenous agricultural practices in Burkina Faso: case of RBMH*. Presentation at the CAZRI International conference on Nurturing Arid Zones for People and the Environment: Issues and Agenda for the 21st Century, 26–29 November 2009, Jodhpur, India.

Poda, J.N., Belem, M., Dibloni, O. 2009. *Sustainable Management of Marginal Drylands (SUMAMAD): Country presentation on Mare aux Hippopotames réserve de la biosphère in Burkina Faso* at SUMAMAD Workshop, 24–25 November 2009, Jodhpur, India

Poda, J.N., Belem, M., Dibloni, O., Ouédraogo, R.L., Kabré, A., Taïta, P. 2010. *Lessons learned on biodiversity management in the biosphere reserve of the hippopotamus pond of Burkina Faso*. Presentation at the International Symposium on Biodiversity, 9-10 November 2010, Alexandria, Egypt.

Poda, J.N. 2010. *Sustainable Management of Marginal Drylands (SUMAMAD): Country presentation on Mare aux Hippopotames réserve de la biosphère in Burkina Faso* at SUMAMAD Workshop, November 2010, Alexandria, Egypt,

Poda, J.N., Yonkeu, S., Wethe, J., Maiga, H., Manpouya, M. 2011. *Conflicting water management within the context of resource scarcity in Sahel*. Presentation at the 3rd Water ARID Conference, 30 May–5 June 2011, Paris, France.

Dibloni, O.T. 2011. *Impact des activités anthropiques sur la dynamique de la faune sauvage dans la Réserve de Biosphère de la Mare aux Hippopotames en zone sud soudanienne du Burkina Faso : Cas de l'hippopotame commun (Hippopotamus amphibius L.)*. Thèse de doctorat èn Sciences Biologiques Appliquées. UFR-SVT/UO, Burkina Faso. 126p+ annexes.

Poda, J.N., Belem, M., Dibloni, O. 2011. *Sustainable Management of Marginal Drylands. Country presentation on Mare aux Hippopotames biosphere reserve in Burkina Faso* at SUMAMAD Workshop, 5-6 December 2011, Bobo-Dioulasso, Burkina Faso.

Dibloni, O.T., Soulama, S., Ouedraogo, I., Guenda, W. 2012. Feeding Habits of Hippopotamus amphibius and Carrying Capacity in the Biosphere Reserve of 'Mare aux Hippopotames' in the South-Sudanian Zone of Burkina Faso. Pakistan *J. Zool*., vol. 44, No. 2, pp. 433–442.

Poda, J.N., Belem, M., Dibloni, O.T., Ouedraogo, A. 2012. *Enjeux de l'utilisation durable des ressources naturelles : cas de la réserve de biosphère de la mare aux hippopotames du Burkina Faso*. In: AfriMAB Biosphere Reserves Showcasing Sustainable Development. (In press)

Poda, J.N., Dibloni, O.T., Belem-Ouédraogo, M., Hébie, L. 2012. *Zonage et gestion durable des ressources naturelles: cas de la Réserve de Biosphère Transfrontière (RBT) du W (Bénin, Burkina Faso, Niger)*. In: AfriMAB Biosphere Reserves Showcasing Sustainable Development. (In press)

Poda, J.N., Belem, M., Dibloni, O. 2012. *The National annual progress report of the project's second phase (2012): case of Mare aux Hippopotames Biosphere Reserve in Burkina Faso*. Presentation at the Tenth International Workshop on Sustainable Management of Marginal Drylands – Phase 2 (SUMAMAD-2), 10–15 November 2012, La Paz, Bolivia.

11. References

Baijot, E., Barry, I., Ratjs, F. 1994. *Peuplements piscicoles des retenues du Burkina Faso*. In: Baijot E., Moreau J., Bouda S. Aspects hydrobiologiques et piscicoles des retenues d'eau en zones soudano-sahélienne. CTA-CEE, Bruxelles.

Belem, O.M. 2008. *Les galeries forestières de la Réserve de la Biosphère de la Mare aux Hippopotames du Burkina Faso : caractéristiques, dynamique et ethnobotanique*. Thèse de doctorat ès Sc. Nat, UFR/SVT, Ouagadougou, p. 282.

Bonkoungou, G.E. 1985. Ruptures d'équilibres écologiques et lutte contre la désertification au Burkina Faso. *Rivista di agricoltura subtropicale Trimestral* ANNO LXXIX (162), pp. 327–343.

Couteron, P., Barthélemy, D., Fournier, J., Busson F., Gallner J.P., Bakyono E., Bedel, J. 1989. *Réserve Biosphère de la Mare aux Hippopotames : étude préalable à un aménagement de la Réserve et de sa zone périphérique*. ENGREF, Montpellier, p. 56 .

Dibloni, O.T. 2011. *Impact des activités anthropiques sur la dynamique de la faune sauvage dans la Réserve de Biosphère de la Mare aux Hippopotames en zone sud soudanienne du Burkina Faso : Cas de l'hippopotame commun (Hippopotamus amphibius L.)*. Thèse de doctorat ès Sciences Biologiques Appliquées. UFR-SVT/UO, Burkina Faso. 126p+ annexes.

INSD, 2000. *Profil et Évolution de la Pauvreté au Burkina Faso*. Ministère de l'Économie et des Finances; Direction des Statistiques Générales, Étude Statistique Nationale, Première Édition, Ouagadougou, Mars 2000.

Lévêque, C., Paugy, D., Teugels, G.G. 1990*a*. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. *Faune tropicale XXVIII*. TOME I. ORSTOM/MRAC, Paris/Tervuren, p. 384.

Lévêque, C., Paugy, D., Teugels, G.G. 1990*b*. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. *Faune tropicale XXVIII*. TOME II. ORSTOM/MRAC, Paris/Tervuren, p. 512.

Poda, J.N. 1990. *La réserve de la biosphère de la Mare aux Hippopotames du Burkina Faso : évolution*. Presentation at the subregional meeting of the MAB national committees of the English speaking countries in West Africa and Cameroon and Burkina Faso, 21–25 October 1990, Ibadan, Nigeria.

Poda, J.N., Belem, M., Dibloni, O.T., Ouédraogo, A. 2012. *Enjeux de l'utilisation durable des ressources naturelles : cas de la réserve de biosphère de la mare aux hippopotames du Burkina Faso*. In: AfriMAB Biosphere Reserves Showcasing Sustainable Development. (In press).

Poussy, M, Bakyono, E. 1991. *Aménagement de l'habitat de l'hippopotame. Mare aux hippopotames*. Report of the UNESCO/BREDA-IRBET/CNRST project, Ouagadougou, p. 40.

Roman, B. 1966. Les poissons des hauts-bassins de la Volta. Annales du Musée Royal de l'Afrique Centrale, *Sciences Zoologiques*, Série 8, pp. 150–191.

Sall, P.N., Maiga, A.Y., Poda, J.N. 1997. *Agro-sylvo-pastoralisme: l'expérience du projet RCS-Sahel*; Livre en Recherche et Développement; UNESCO–BMZ working group - Institut du Sahel, p. 196.

Sanon, Z.L. 1995. *Inventaire et dynamique de quelques espèces de poissons dans la Réserve de la Biosphère de la mare aux hippopotames et dans le lac de la vallée du Kou*. Memoire d'Ingéniorat de l'Institut de Développement Rural de Ouagadougou.

Sustainable Management of the Restored Hunshandake Sandland: Basic Scientific Research and Income Generation

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1. Introduction

Hunshandake Sandland (41°56' – 44°22'N, 112°22' – 117°57'E, 1,100–1,300 m a.s.l.) is located in the middle of Xilingol Plateau, China's Inner Mongolia municipality. It is one of the four major sandlands of China, starting from the east Dali Lake via the Southwest Great Xing'an Mountain, and extending to Jining-Erlian to the west. The length of Hunshandake Sandland is about 450 km with a breadth of 50–300 km and a total area of 53,000 km² (Fig. 1). It encounters strong wind throughout the year, especially in late autumn and early spring, with an average wind speed of 3.5-5.5 m/s, reaching a maximum 24-28 m/s. For 60–80 days in a year, the area experiences wind velocity of >8 degrees. The climate can be characterized as temperate semi-arid type with mean annual temperatures of 0.5–3.5°C, mean annual precipitation of 250–400 mm, and mean annual potential evaporation of 2,000–2,700 mm. However, more than 50 per cent of the annual rainfall is concentrated in July and August, during which the highest monthly mean (July) can see temperature peaks of 17°C. This special climate is particularly vital for plant growth.

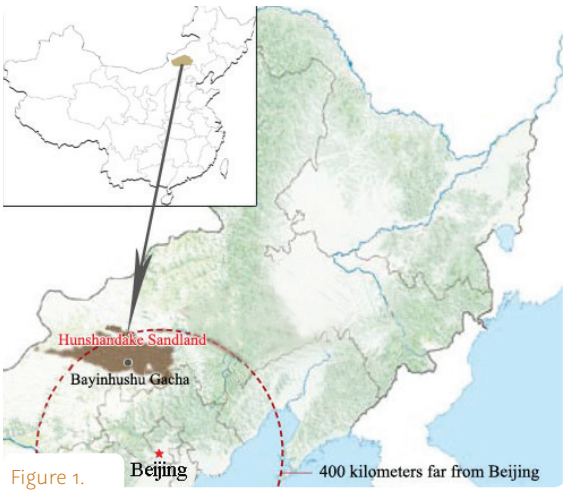

Figure 1.
Sketch of Zhenglan Banner with a view on the location of Bayinhushu Gacha (village) where the SUMAMAD Hunshandake Sandland project is located. © Prof. Jiang Gaoming

In the semi-arid areas of north China, sandstorms rank among the most serious environmental calamity, posing threats to both animal husbandry and social sustainability. It is reported that serious annual sandstorms hitting the capital city Beijing and regions nearby originate from three main sources: degraded grasslands, croplands in the steppe region, and dried-up lakes in the arid and semi-arid regions (Dong *et al*., 2004; Yang *et al.,* 2005). Years of overgrazing have led to remarkable grassland degradation in north China, causing further ecological disasters such as the proliferation of insect pests, and the appearance of sandstorms or light windborne dust clouds in China and neighboring countries such as Korea and Japan (Akiyama and Kawamura, 2007; Jing *et al*., 2002; National Environmental Protection General Agency, 2005).

The entire Hunshandake Sandland consists of five main habitats, comprising fixed sand dunes, semi-fixed sand dunes, shifting sand dunes, lowlands and wetlands. The main soil type is chestnut aeolian sandy soil. Siberian elm (*Ulmus pumila*) is the most importantly dominant tree species, growing sparsely and unevenly in the sandland and forming the sparse forest grassland landscape. Such a landscape is mainly composed of a dense herbaceous layer with some shrubs and sparse trees distributed throughout the grasslands.

With a population of 128,000, before the SUMAMAD project started in 2004 (first phase 2004-2008), Hunshandake Sandland now functionally acts as pure pasture – 92 per cent of its income is derived from livestock breeding. Among the different animals, cattle comprise 24 per cent, goat 35 per cent, and sheep, horse and camel together make up 41 per cent. As the largest Banner ('county' in Mongolian) in Hunshandake Sandland, Zhenglan Banner has a

human population of 73,000, 40 per cent of whom are Mongolian. This is a much larger percentage than the average for Inner Mongolia (12 per cent). The rapid increase in animal numbers occurred during the last decade of the twentieth century, with the highest recorded number of animals (more than 1 million) in 1990. The rapid increase of middle-sized animals, especially goats and sheep, was considered as one of the principal reasons for the severe degradation of the sandlands in China.

The average annual income of a herdsman in Hunshandake between 1960–1990 was less than 1,000 RBM (US$ 160) when the whole country was in a less developed state. Today, this figure is about 2,910 CNY (US$ 470). The ratio of income from stock production to gross domestic product (GDP) has shrunk, while income from industry and other activities has increased. Some parts of traditional stock production have been gradually replaced by modern stock production methods (restricted grazing, breed selection, and so on), related agribusiness and other industries.

Although there has been substantial government allocated funding for the restoration of degraded grassland to projects, including tree planting, fencing grassland or rearing dairy milk cows, most of those efforts are short-lived and ineffective relative to the huge investments on the grassland (Kawamura *et al*., 2005; Li and Zhang, 2009). Based on the findings of a large-scale (2,667 ha) and long-term (ten years, 2000-2009) experiment in the Bayinhushu village of the Hunshandake Sandland in the northern grassland of China. In the SUMAMAD project, we have proposed a novel alternative strategy which utilizes natural grasslands as an ideal place for chicken farming instead of the traditional model of raising cows and sheep.

The basic conclusion from Phase I (2004–2008) of the SUMAMAD project in Hunshandake Sandland was that the degraded grassland could effectively become restored once the huge animal pressure has been removed (Liu, 2004; Jiang *et al*., 2007; Li *et al*., 2007; Normile, 2007). Furthermore, our experiments have yielded great results, essentially requiring an urgent shift in the land use systems. In order to maintain and to enlarge the application of achievements during project phase I, and to sustainably manage the vast grassland in Hunshandake, an innovative approach was promoted using poultry to replace sheep and goats, and using milk cattle to replace meat cattle. According to our experiences over the last ten years, any restoration project without adequate economic outputs for the local people will fail, regardless of whether they are governmental or non-governmental projects. Therefore, in Phase II of SUMAMAD (2009–2013), we established a demonstration project involving some families in the project site, to show the local people how our proposed solution can generate higher incomes, while causing little damaging to their lands.

2. Improved dryland agriculture and rehabilitation of degraded areas

With the rapid increase in the human population and livestock, the grazing pressure on the pasture of Inner Mongolia, China, has amplified seven fold over the past 20 years. The grasslands in Hunshandake Sandland – one of the most important pastures in Inner Mongolia – had gradually become degraded, leading to frequent sandstorms. In solving land degradation there, different restoration practices have been applied: i) tree planting or aerial seeding of selected shrubs or trees; and ii) fencing the degraded land to exclude grazing, allowing natural

regeneration based on the exact soil seed banks. However, although there has been substantial government allocated funding for the restoration of degraded grassland in projects such as tree planting, fencing grassland or rearing dairy milk cows, most of those efforts are short-lived and ineffective relative to the huge investments on the grassland. Based on the findings of a large scale (2,667 ha) and long-term (2000-2009) 10-year experiment in the Bayinhushu village of the Hunshandake Sandland in the northern grassland of China, SUMAMAD Phase II proposed a novel alternative strategy that utilizes natural grasslands as an ideal place for chicken farming instead of the traditional model of raising cows and sheep (Liu *et al*., 2013). The experiment was designed to test whether chicken farming in grassland can slow degradation and yield more profit than traditional sheep-raising. It illustrates the feasibility and advantages of chicken farming in grasslands, offering a new perspective for maintaining future grassland sustainability.

Chicken farming in grassland caused a significant increase in primary production compared to traditional sheep grazing ($P<0.01$), with the former yielding three times the above ground, and twice the root biomass of the latter. Chickens fed with corn significantly increased the Important Value Index (IVI) of Poaceae ($P < 0.05$), whereas those fed with both insects and corn enhanced the IVI of Brassicaceae (Fig. 2), suggesting that the selective foraging of animals, i.e. chicken versus sheep and a protein supplement in the form of insects changed chicken foraging behaviour. In comparison with the unstocked and fenced grassland, chicken farming did not significantly decrease above ground production, but significantly enhanced the accumulation of root biomass ($P<0.01$), with an increase of 60% over that of the fenced control grassland. Nevertheless, chickens fed with both corn and insects did not significantly influence root biomass, with only a non-significant 7% increase in comparison with the control. This result clearly implied that the chickens fed with both corn and insects had little impact on grassland productivity. The association of above ground biomass and root biomass was analysed to determine whether the grazing pattern impacted on the partitioning of biomass.

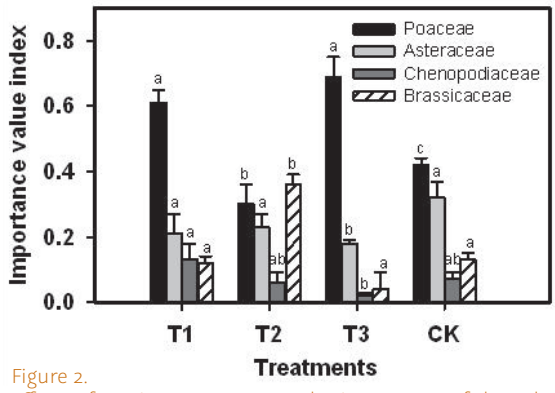

Figure 2.
Effects of grazing treatment on the importance of the value index of species belonging to four plant families: Asteraceae, Chenopodiaceae, Poaceae and Brassicaceae. Values are mean ± SE (n=4). Abbreviations for treatments are defined in Figure 1. Columns with different letters indicate significant differences at $P < 0.05$. Abbreviations T1: chickens fed with corn; T2: chickens fed with both corn and insects; T3: traditional sheep grazing; CK: the control without grazing. Columns with different letters indicate significant differences at $P < 0.05$.

Free-range chicken in grassland significantly reduced above ground biomass (in dry weight) by 32% ($P<0.001$) without statistical difference between different supplementation treatments (Fig. 3). However, the above ground biomass in chicken grazed plots was 3.1 times that in sheep grazed plots. It is possible that under the stocking rate of this experiment, chicken grazed less than sheep. Furthermore, chicken could be sold when fully developed before the harsh cold season arrives. Nevertheless, herdsman usually feed stock during winter so they need to stock more grass for winter, which further aggravated the pressure on grassland. The allocation of biomass (root: shoot ratio) was also significantly changed by sheep grazing ($P=0.005$), while chicken grazed plots showed

no significant difference from the control group. Therefore, from the aspect of grassland biomass, chicken farming was more environmentally friendly than sheep grazing.

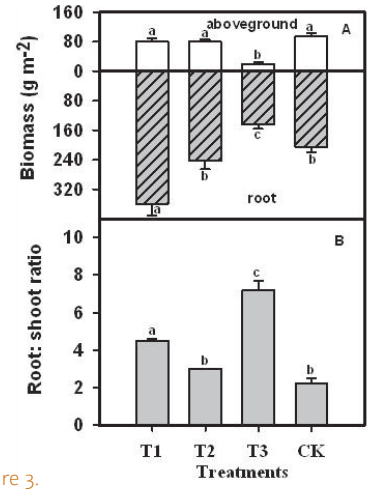

Figure 3.
Effects of grazing treatment on above ground and below ground plant biomass (A) and root: shoot ratio (R: S) (B). Values are mean ± SE (n=4). Abbreviations are the same as Figure 2. © Prof. Jiang Gaoming.

To compare the results of natural restoration of degraded grassland, we have examined the species composition and seed density of soil seed banks and above ground vegetation compositions between naturally restored habitats and aerial seeding sites in Hunshandake Sandlands. Natural restoration habitats comprised five sites (NRS15, NRS8, NRS4, NRS2 and NRS1 – with numbers denoting year since fencing), according to the year of close-up, fenced respectively in 1987, 1993, 1998, 2000 and 2001. The aerial seeding sites (ASS7, ASS5, ASS2 and ASS1), were fenced after aerial seeding in 1995, 1997, 2000 and 2001, respectively. Thirty-six species appeared in soil seed banks of the naturally restored habitat, with 41 species being noted in the above ground vegetation. Two pioneer species, i.e. *Agriophyllum squarrosum* and *Setaria viridis*, occurred in the seed bank of NRS1. Species numbers elevated to 25 at NRS15. Although both pioneer species still occurred in the seed banks of NRS8 and NRS15, the probability of re-establishment was pretty low.

More than 50% of species were perennial in the seed banks of all four sites and C3 plants represented 40-50% of the species composition, except for the ASS1 site, with legumes being found at all sites (Fig. 4). At naturally restored sites, annual species dominated either in the above ground vegetation or the seed banks of NRS1 and NRS2. The seedlings of *Ulmus pumila* (an indigenous tree species) established well in all naturally restored sites. Aerial seeding areas were dominated by most alien shrub species, e.g. *Artemisia ordosica* and *Hedysarum scoparium*. The establishment of introduced species might limit the germination of certain indigenous pioneer species. Seed density was significantly different between naturally restored and aerial seedling sites, which increased from 459 ± 76 to 3302 ± 315 seeds m^{-2}, with the close-up time extending from 2 to 8 years, while it was 181±62 and 669±213 seed m^{-2} respectively in ASS2 and ASS7. The investigation showed that the seed bank is large enough to allow natural restoration of the degraded Hunshandake Sandland. Our findings suggested that it is not always essential to introduce alien species in enhancing vegetation coverage in such a region (Liu *et al.*, 2009).

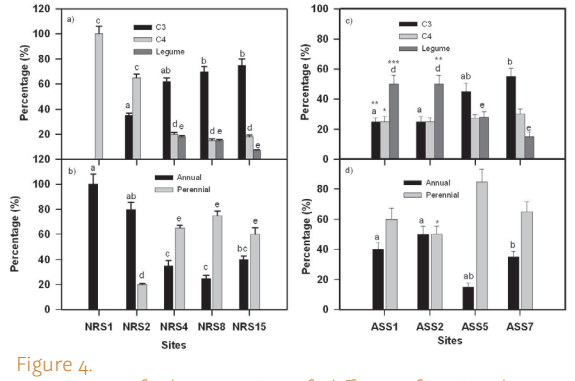

Figure 4.
Percentage of plant species of different functional types (C3, C4, legume and annual, perennial) that had changed with the restoration process above ground in vegetation at natural restoration sites (a,b) and aerial seeding sites (c,d) in Hunshandak Sandland. © Prof. Jiang Gaoming

Natural restoration of the degraded grassland ecosystem in Hunshandake Sandland largely relies on the abilities of groundwater. Along with the increase of Underground Water Level (UWL), the upper ground and below ground biomass, the species numbers and coverage decreased, while the Simpson, Shannon Weiner Index and Average Index decreased (Table 1) owing to the fact that sandland species depend on groundwater in dry seasons. Data analysis further showed that when UWL became deeper, species like annual grasses disappeared, leaving only those shrubs or trees (*Ulmus pumila*) that can tolerant the dry habitats and highly saline water. The average biomass (9.19 Mg C ha^{-1}) and NPP (4.79 Mg C ha^{-1} yr^{-1}) of the recovered sandland were respectively 82% and 54% higher than the mean level of the surrounding temperate grassland. Governed by the same climate, sparse forest grassland ecosystem had a RUE (Rain Use Efficiency) almost twice that of the surrounding grassland. The ratio of below to above ground biomass was 3.5: 1 in the Hunshandake Sandland, indicating that most of the vegetation carbon was stored in the below ground pool (Li *et al*., 2011).

TABLE 1.
CHANGES OF PLANT BIOMASS AND BIODIVERSITY INDICES ALONG WITH GROUNDWATER TABLE

No.	Water table [m]	Upper Biomass [g]	Below Biomass [g]	Coverage	Species	Number	Simpson	Shannon -Weiner	Average
01	0.91	88.00	430.96	100	17	669	0.56	2.15	0.52
02	0.93	111.40	511.08	100	15	255	0.82	2.95	0.76
03	0.95	119.44	237.60	100	21	302	0.86	3.33	0.76
04	1.10	348.68	729.48	100	12	505	0.76	2.40	0.67
05	1.16	160.80	741.60	95	13	392	0.86	3.09	0.84
06	1.18	179.92	478.64	98	11	461	0.83	2.79	0.81
07	1.84	43.88	396.08	75	16	241	0.84	3.07	0.77
08	1.85	31.56	320.88	75	13	180	0.69	2.32	0.63
09	1.87	21.08	339.16	75	15	222	0.79	2.74	0.70
10	2.21	81.68	594.56	65	11	434	0.65	2.03	0.59
11	2.24	93.72	502.84	55	10	327	0.74	2.34	0.70
12	2.28	35.24	451.92	60	13	401	0.77	2.53	0.68
13	3.31	32.88	157.12	45	9	174	0.80	2.50	0.79
14	3.33	27.32	104.80	45	9	127	0.73	2.23	0.70
15	3.34	108.08	462.88	50	10	68	0.82	2.76	0.83
16	3.36	24.04	97.24	45	13	394	0.75	2.46	0.67
17	3.40	85.08	501.24	45	14	357	0.70	2.35	0.62
18	3.42	74.40	568.88	45	11	339	0.47	1.65	0.48
19	4.41	74.56	413.72	30	9	283	0.67	2.10	0.66
20	4.43	72.44	419.36	30	8	283	0.69	2.14	0.71
21	4.48	44.92	274.92	30	11	298	0.72	2.33	0.67
22	4.85	23.76	121.24	30	8	306	0.62	2.00	0.67
23	4.87	30.16	266.52	30	9	219	0.68	2.09	0.66
24	4.88	28.36	297.80	30	13	202	0.78	2.57	0.70
25	6.40	23.04	432.85	15	12	271	0.71	2.34	0.65
26	6.43	22.16	420.84	15	12	303	0.57	1.97	0.55
27	6.44	17.00	230.40	15	11	181	0.80	2.59	0.75

In the SUMAMAD project, the serious land degradation in Bayinhushu Gacha (village in Mongolia language) has been controlled with plentiful sandland vegetation having been recovered, while dust storms ceased in the demonstration area. The local herdsmen no longer bought forage from distant areas during winter and early spring, selling the superfluous forage to the market (Jiang *et al*., 2012). Herdsmen of Bayinhushu now have their own driveway, grid electricity, new houses, tap water and bathrooms, with living conditions having improved significantly. The largest experimental demonstration site in China's grassland of 'replacing livestock with poultry' was established (Fig. 5). The successful restoration in Bayinhushu, especially in the case of desertification prevention and biodiversity conservation, has been intensively reported by academic journals and media both nationally and internationally.

Figure 5.
The largest experimental demonstration site in China's grassland to 'replace livestock with poultry'.
© Prof. Jiang Gaoming

3. Scenarios for future land use changes

The project site of Bayinhushu Gacha consists of 72 households with 316 people and 11,560 head of livestock with 75 per cent sheep and goats and the rest cattle. The village now manages 7,330 hectares of land, much of it communal pasture. The main actions toward land restoration and income generation include the following: i) using small areas of land to nurse the large natural land (strictly fenced), 1000 mu (1 ha=15 mu) of grassland was intensively cultured with plentiful groundwater to grow corn for the animals living in winter and early spring, encouraging the natural restoration of the grassland; ii) introducing new income generation activities such as chicken farming, traditional organic milk tofu, ecotourism, forage harvest, and industrial process of the natural grasses to increase the income of the local people in the large fenced areas; iii) decreasing animal numbers, especially goats that cause serious land disturbance, while keeping a suitable amount of milk and meat cattle (from 50–60 heads down to 10–20 heads).

After 10 years (2004–2013) of demonstration, the SUMAMAD project yielded great results both at home and abroad. Because of the continuing impacts of the demonstration project in Hunshandake Sandland, and thanks to the contribution from numerous media, relevant policy has changed at both the national and local levels. We trained the local people to conduct new, environmentally health and economically effective activities such as chicken farming (Fig. 6) and organic milk tofu prodution (Fig. 7). Most of the activities such as chicken farming and ecotourism were carried out by women only, as they are less labour intensive. While the heavy labour, such as forage harvesting and processing,

and organic food marketing were carried out by men from the local families.

Figure 6.
Local famers especially women were trained to conduct the environmentally healthy, economically effective and labour saving activity of chicken farming. © Prof. Jiang Gaoming

Figure 7..
Mr Bater Hasi on his way to selling his organic milk tofu. © Prof. Jiang Gaoming

Land ownership was one of the main reasons behind land degradation; land was divided into small holdings by local herdsmen. Consequently the project advocated a contractual system of land responsibility. Notions put forward aimed at the sustainable management of Hunshandake Sandland include 'restore the nature naturally', 'use small parts of land to nurse the large natural land' and 'replace cattle and goat with poultry'. We set up a grassland reserve and cultured forages for the animals in a small part of the study village, while a large part of the area was enclosed for recovery by natural process.

Based on the findings of the SUMAMAD Hunshandake Sandland project, we have proposed raising chickens in relatively small areas of land (10 per cent of the total) with a water source, while leaving the other large degraded land areas (90 per cent) for natural restoration. Since soil seed banks in these grasslands are sufficiently large to sustain re-vegetation (Liu *et al.*, 2009), no further human efforts were required. It is important to note that by adopting this strategy, the income of the local herdsmen has not decreased, but has in fact doubled. Chickens allowed to roam freely on family farms can eat sufficiently natural foods such as insects, fresh green foliage and seeds, which can hardly be found in cropland areas (Wuyu *et al.*, 2010). In addition to important welfare benefits, the Mongolian people enjoy a stress free life, breathe fresh air, and drink clean water. More importantly, moving chickens daily to a new area minimizes contact with wild animals or birds, and reduces the risk of transmitting infectious diseases. Chicken litter also benefits the production and soil quality of the grassland ecosystem, with few side effects on its structure and function (Wang and Jiang, 2011).

For this huge demonstration experiment (10,000 km^2) in China's vast grassland, the project team explored the possibility of establishing the largest Eco-husbandry Industry Demonstration Region in China's grassland by using a new land use strategy (Fig. 8). The huge efforts were made together with the Institute of Botany at the Chinese Academy of Sciences (CAS), and The Academy of Grassland and Husbandry of Inner Mongolia. The design of the first eco-husbandry project in China situated in Zhenglan

Banner has been completed by our Hunshandake project team. The contribution from the SUMAMAD Hunshandake team yielded such remarkable results that the Inner Mongolia government has agreed to provide an amount of 100 million Chinese Yuan (CNY) to study the key scientific and social problems in the eco-husbandry region. Meanwhile, CAS has approved a project amount of 9 million CNY to explore the technological issues arising in limiting the construction of the largest Eco-husbandry Industry Special Region.

Figure 8.
A sketch showing the features of the Eco-husbandry Special Region in China, based on the findings of the SUMAMAD project. © Miss Lijing and Prof. Jiang Gaoming

4. Ensuring sustainable livelihoods through alternative income-generating activities

It is vital to explore an alternative approach to a more sustainable utilization of grassland resources without causing further land degradation. According to the past decade of ecological restoration in Hunshandake Sandland of Inner Mongolia, to efficiently protect grasslands we need first to reduce overgrazing pressure, while trying to find alternative ways to maintain or increase the income of the local people. Previous ecological projects on grassland management have tended to consider increasing primary production artificially, i.e. by promoting the growth of grasses and forbs in the ecosystem. Our alternative approach considers to partially replace the major consumers in the grassland ecosystem, such as cattle or sheep, with less destructive animals such as chicken.

The main actions towards income generation include the following:

- Introducing new income generation activities such as chicken farming. During the past four years, some 50,000 free-range chicken have been raised, with the chicken products being officially certified and marketed in Beijing. Local people such as Nasen Wuritu, Huhe Tuge can now earn 100,000 CNY (US$ 16,000), making them much happier with this new income activity (Fig. 9).

- Helping the local people to develop the traditional milk tofu and dairy cattle raising and selling, with eight households involved in such activities.

- Greenhouses in the project site will be built to grow vegetables using organic fertilizers from chicken and cattle.

- Forage harvest and the industrial processing of the natural grasses to increase the income of the local people in the large fenced areas. Some families, especially those raising free-range chicken, sold all their mammals so their grasses can now enter the market, which can yield 30,000 CNY per family (US$ 4,800).

- Ecotourism has been conducted in the summer period, with three to five families making reasonable profit from the numerous visitors wishing to experience the chicken farming in the grassland.

Figure 9.
Huhe Tuge happy with his free-range chicken. He sold all his animals and harvested hay while concentrating on raising grassland chicken. © Prof. Jiang Gaoming

For chicken farming in particular, the SUMAMAD team coordinated and helped Bayinhushu Gacha (the project village) to establish the Zhenglan Banner Zhongke Scientific and Technological Development Company. The main funding came from Mr Zhou Shengxiang, Shenzhen Meijiamei Investing and Development Company who was attracted by the SUMAMAD project. Two scientists from Shengyang Institute of Applied Ecology of the Chinese Academy of Sciences were also involved with this activity. The specially established company aims to produce and market the grassland chicken, with the local government helping to set up the company (Fig. 10). Mr Bagenna and Mr Siqibilige, head of Zhenglan Banner, kindly provided valuable assistance in establishing the new company.

Figure 10.
Officials from Zhenglan Banner helped Mr Zhou Shengxiang in establishing the Zhenglan Zhongke Scientific and Technology Limited Company to develop chicken farming in Hunshandake Sandland. © Mr. Zhu Rusheng

Farmers have been trained in carrying out the new income generation activities. Eleven household farmers participated and 22,000 chickens were rented by farmers, while chicken houses were built in the grassland. Large areas of the grassland have been protected from overgrazing by large and middle-sized animals. To protect the chicken from wild animals such as fox and eagles, we designed special moveable chicken houses using native shrubs (Fig.11). Most of the activities such as chicken farming and ecotourism were solely carried out by women, as they are less labour intensive. Such heavy labour as forage harvesting and processing, and organic food marketing were carried out by the men from local families.

Figure 11.
Chicken house build from local plant material – willow twigs. © Prof. Jiang Gaoming

The new land use patterns of chicken farming, baby cattle breeding, and organic tofu production have tested successfully in the demonstration households of Bayinhushu Gacha (village) in Zhenglan Banner (county). In the case of Huhetuge's family, he earned around 50,000 CNY in selling free-range chicken, 30,000 CNY in selling organic eggs, and another 30,000 CNY in selling the harvested hay. He replaced all his cattle and sheep with chicken and most of his 150 ha of grasslands are free from big animals, allowing him to harvest plentiful quantities of hay for the markets. Compared with traditional sheep grazing, chicken farming significantly improved soil surface water content (0–10 cm), from 5% to 15%. Chicken farming did not affect the soil bulk density, while traditional sheep grazing increased the soil bulk density of the 0–10 cm soil layer. The economic income of local herdsmen has risen six fold compared to the traditional practice of raising sheep. Ecologically, such an innovative solution allowed a large area of degraded land to regenerate.

Chicken farming is an alternative pathway to ecological restoration that greatly enhances the income of local people compared with traditional grazing. Simultaneously, the naturally restored grasses can be sold as hay, thus further increasing the income of the local population. The grassland was equally divided among people based on local population and grassland productivity, with an average of 30 ha of grassland per person in the study area. Equal-sized families will therefore possess a

TABLE 2.
ECONOMIC BENEFITS OF CHICKEN FARMING, TRADITIONAL SHEEP GRAZING AND NON-GRAZING PER HECTARE OF GRASSLAND

Data for chicken farming were up-scaled to one hectare based on the data collected from our experimental 100 m² plots; data for traditional sheep grazing were collected in 5000 m² experimental plots. The input refers to the costs for purchasing corn, immunization for chickens, and the cost of UV lights, excluding environmental costs and labour. The outputs include the sales of hay produced from the grasses and of the animals / chicken.

	Parameters	Sheep grazing	Chicken farming (fed corn)	Chicken farming (fed corn + insects)	Control
Input	Corn amount (kg)	0	2615a	2418a	0
	Cost of corn (US$)	0	392.3a	362.7a	0
	Cost for immunization and hatching (US$)	0	1109.5	1109.5	0
	Cost of UV light (US$)	0	0	115.3	0
Output	Body mass increment of animals/chicken (kg)	20.8 ± 0.9a	510.9 ± 0.7b	520.5 ± 0.6b	0
	Income from animals / chicken (US$)	246.1a	3024.5a	3081.4a	0
	Harvestable plant biomass ('103kg)	0	0.82 ± 0.6a	0.81 ± 0.7a	0.94 ± 0.4a
	Income from hay (US$)	0	59.9a	59.1a	68.6a
Net output	Income of herdsmen (US$)	246.1a	1582.6b	1644.7b	68.6c

Note: The income for all products was calculated based on the local market price in 2010. The price of chicken was 5.92 US$ per kg (1.0US$ = 6.76 Chinese Yuan); the lambs were 11.83 US$ per kg; the price of hay was 0.073 US$ per kg; and the price of corn was 0.15 US$ per kg. The life span of UV light lamps was assumed to be five years and the average input was 23.6 US$ for each year. Means followed by different letters were statistically different among treatments at the $p < 0.05$ level.

comparable area of grassland, and generally there are four to five people per family in local communities. In 2010, in Bayinhushu village – where our experiment was conducted – a 5-person family typically raised 5,000 chickens instead of sheep and cattle, and earned US$ 4,760 just from selling hay. The income from hay alone was equivalent to 85 per cent of a local family's typical annual income. The SUMAMAD project revealed that the economic benefits of chicken farming was about six times greater than that of grazing sheep per hectare of grassland (Table 2). Grassland chicken farming therefore ensures the sustainability of Inner Mongolia communities from both an economic and ecological point of view.

Before the SUMAMAD project, more than 90 per cent of local families had to invest appreciable funds, averaging 10,000 CNY (US$ 1,600) to buy forage grass from distant sources for their livestock. New income generation activities have been realized such as chicken farming and traditional product marketing such as milk tofu and milk wine. The local people have increased their income by 3.71 fold, from US$ 315 to US$ 1,206.

5. Recommendations for sustainable dryland management

As for policy relevant analyses, we have focused on:

- Developing scenarios for land use change: First, the lands are restored through natural processes without large and middle-sized animals. Second, chicken are freely raised in the grasslands with insects being controlled and fertilizers being added. Third, forages are harvested and processed to increase income. Fourth, dairy industries and other organic foods are developed with markets being opened in large cities such as Beijing.

- Upon the success of the proposed project, we have formulated suggestions on the sustainable management of the Inner Mongolia grassland for policy makers and China's top officials through Xinhua News Agency – the most influential media in China.

- In the context of climate change, resulting in higher temperatures and reduced precipitation, the net primary production (NPP) of the grassland could no longer support the increase of traditional stockbreeding of large livestock. Accordingly, new land use systems were considered. A low carbon economy is the key to this project, as more NPP will be enabled and less grain consumed from the national point of view.

- The economic income of local herdsmen has risen six fold compared with the traditional practice of raising sheep. Ecologically, such an innovative solution allowed a large area of degraded land to regenerate.

The SUMAMAD Hunshandake project has had a remarkable influence both locally and internationally. Since 2004, when the SUMAMAD Phase I first started, some 218 articles or interview papers have been published in top newspapers such as the *People's Daily, Guangming Daily* and *Xinhua News Agency*. Six important recommendations have been proposed, with four being delegated by top officials such as Premier, Wen Jiabao, and Vice Premier, Hui Liangyu. Television programmes appeared in CCTV, BTV, the Phoenix (Hong Kong), with 12 series lasting some 400 minutes that broadly promoted our achievements in Bayinhushu Gacha, the project site. International newspapers and journals such as Science, New York Times, France 2, Der Spiegel (Germany), Al Jazeera,

Chicago Tribune News, and NOVA Powderhouse Productions also spoke of the results from our project site. In addition, we have published two books and 32 scientific papers.

On 20 July 2007, Science Magazine published a special article in its News Focus column, introducing our achievements in Hunshandake Sandland with the title *Getting at the roots of killer dust storms*. The report brought great attention to the project, precipitating policy changes in China's desertification control and dryland management programmes. In May 2008 in New York, UNESCO exhibited the achievements of the SUMAMAD project from the eight participating countries from Phase I; the Hunshandake case being mentioned many times in the poster. Two books, *People in Marginal Drylands: Managing Natural Resources to Improve Human Well-being* and *Using Science to Promote Sustainable Development: SUMAMAD Project Findings from Northern Africa to Asia* have been published, which also introduced the achievements of the Hunshandake site. A US college textbook *Geology and the Environment* (6th Ed) by Prof. Nard Pipkin, D.D. Trent, Richard Hazlett and Paul Bierman (2010) also referenced the achievements from our case study in Bayinhushu Gacha, Hunshandake Sandland (Fig. 12).

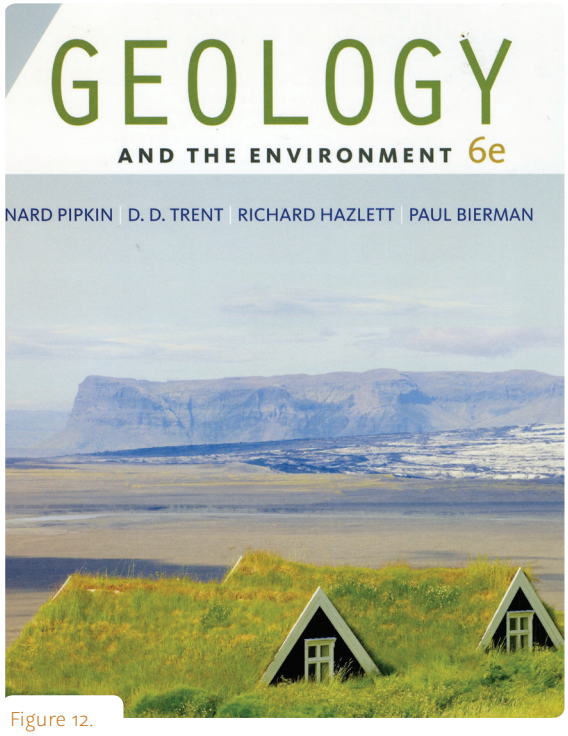

Figure 12.
Cover of the US college text book Geology and the Environment (6th Ed.) by Prof. Nard Pipkin et al., in which the achievements from our case study in Bayinhushu Gacha, Hunshandake Sandland was referenced (pp. 407–8).

It is also worth mentioning that the SUMAMAD Hunshandake project was a semi-finalist in the first Land for Life Award. In the awards, the following words were pronounced about Dr. Gaoming Jiang from the Institute of Botany, Chinese Academy of Sciences, 'Where many efforts to reverse desertification in northern China have failed, Professor Jiang has proven that by ending the grazing of large livestock and providing the community with alternative livelihoods, land can be naturally restored'. The special award, which is presented for innovative and inspiring inventions to restore degraded land, has been initiated by the United Nations Convention to Combat Desertification (UNCCD) since 2011 to commend and recognize outstanding efforts to promote the natural health and productivity of the Earth's soils. More than 100 applications from 52 countries were submitted in a bid to win the prize, since it is open to individuals, NGOs, governments, businesses, media and any organization that demonstrates its contribution towards sustainable land management.

The successful achievement of the SUMAMAD Hunshandake project has attracted attention from a number of high-ranking officials in China, largely contributing to policy changes. Top officials visiting the project areas included Mr Zeng Peiyan, vice president of the State Council of China (in 2002), Mr Lu Yongxiang, president of CAS (in 2002), Mr

Wang Shucheng, minster at the Ministry of Water Resource (in 2003), Ms Wuyun Qimuge, president of Inner Mongolia (in 2003), Mr Peng Peiyuan, vice chairperson of National People's Congress (NPC) (in 2004), Mr Yang Bangjie, vice chairman of Central Zhigong Party (in 2005), and Mr Ding Zhongli, vice president of the Chinese Academy of Sciences (in 2008 and 2009).

National policy changes have finally been implemented following the success of the project. Since 2006, the task of controlling the sandstorms was lead by the State Development and Inform Committee (formerly State Forestry Administration) with a budget of 60 billion CNY. The model used in Hunshandake Sandland was considered by Mr Hui Liangyu, Vice Premier of the State Council on 26 June 2006. The grassland management policy, highlighting its ecological function, was firstly released by the State Council of China in 2011. In 2012, the State Council decided to continue its support with another 87.9 billion CNY to control the wind-dust resource in the upper Beijing-Tianjin regions (2013–2023). This huge project will include five provinces and cities, including Inner Mongolia, Hebei, Shanxi, Beijing and Tianjin. Some 30 billion CNY will be spent on the natural restoration of the degraded ecosystem. Ten years ago, prior to our project, there was hardly any funding for natural restoration. Locally, Xilingol League has bought and distributed 400,000 chickens to its 10 Banners or counties to control grasshoppers.

The most successful impact of the project, however, is that 'natural restoration' for the rehabilitation of degraded ecosystems has become one of the main principles in establishing eco-civilization, appearing in the new version of the constitution of the Communist Party of China, the world's largest ruling party. The scientific term of 'natural processing' or 'natural restoration' was invented and first used in 2000 by Prof. Jiang Gaoming, the SUMAMAD Hunshandake project team leader.

The project team brought about the concept and explored the possibility of establishing the largest Eco-husbandry Industry Demonstration Region in China's grassland with huge efforts made together with the Institute of Botany, the Chinese Academy of Sciences (CAS), and the Academy of Grassland and Husbandry of Inner Mongolia. The design of the First Eco-husbandry Region in China, based in Zhenglan Banner, has been completed by the Hunshandake project team. The new land use patterns of chicken farming, baby cattle breeding, and organic tofu production have tested successfully in the demonstration households of Bayinhushu Gacha in Zhenglan Banner. Thanks to the huge efforts of numerous scientists, especially the members of the SUMAMAD Hunshandake project team, the Inner Mongolia government agreed to provide an amount of 100 million CNY to study key scientific and social issues in the eco-husbandry region. Meanwhile, CAS has approved a project amount of 9 million CNY to explore the technological issues in limiting the construction of the largest Eco-husbandry Industry Special Region.

6. Research institution and team composition

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Ms Su Benying
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7. List of national seminars

2009

A national seminar was held during 15–18 August in Bayinhushu Gacha, Zhenglan Banner. Field experiences of the 52,000 chickens introduced in the study area – the first and largest new income activity in Inner Mongolia – attracted much interest from the national seminar participants. Mr Ding Zhongli, the deputy president of the Chinese Academy of Sciences (CAS), and Mr Fan Yuming, the head of the Bureau of Nature Resource and Environment at CAS, also attended the seminar. Many well known scientists made presentations during the seminar

including Prof. Wang Tao, director of the Institute of Arid and Cold Zone Engineer and Technology at CAS, Prof. Han Xinguo, director of Institute of Applied Ecology at CAS, Prof. Tian Changyan, Director of Xinjiang Institute of Biology and Geography at CAS, Prof. Zhao Xijia, vice-director of Institute of Botany at CAS, and Prof. Su Heping from Changchun Institute of Geography at CAS. Some 12 leaders from 6 institutes of CAS, and government officials from both county and town levels of Zhenglan Banner, Inner Mongolia, attended the national seminar, including some local farmers and ten working group members. In-depth discussions were explored on:

- How to manage the chickens in the grassland.
- The possibility of ecotourism and marketing.
- National policies related to the restoration of degraded sandlands in other areas of China.

2010

The national seminar was held in Zhenglan Banner from 7–9 August 2010. Experts came from the State Bureau of Forestry, the Ministry of Agriculture of the People's Republic of China, the Chinese Academy of Sciences, Beijing Forestry University, the Forestry Research Academy of China, and the Forestry Research Academy of Inner Mongolia. Leaders from Xilinhot City, Xilinhot Biosphere Research, Zhenglan Banner, and farmers from Bayinhushu Gacha, together with the project's working members attended the national seminar who demonstrated our achievements in the field. The following topics were discussed, and one suggestion by a top official was prepared and accepted by the *People's Daily* (Top Officials edition):

- Scenario building as policy making tools.
- Shift of land use patterns in order to promote both ecological and economic output.
- Carbon sequestration potentials, if the grassland is properly protected.
- Biodiversity changes in grassland and the problems related to chicken farming.
- Water resource utilization, especially ground-water and snow.

2011

From 29–30 October 2011, the national seminar was held in Beijing. Thirty delegates from the Chinese Academy of Sciences, the Chinese Agriculture Academy of Sciences, Inner Mongolia University, Inner Mongolia Agriculture University, Lanzhou University, China Agriculture University, Arizona State University (USA), Beijing Normal University, China Northeast Normal University, and reporters from *Science Times* and *Science and Technology Daily*, attended the seminar. Academician Fang Jinyun, the head of the Institute of Botany, Chinese Academy of Sciences (IBCAS), made a presentation in the seminar and gave an important speech. The main topic was 'Establish the Eco-husbandry Special Region to enhance the sustainable development of economy and society in Inner Mongolia'. The deputy president of the Beijing Branch of the Chinese Academy of Sciences, together with Mr Zhao Cunfa, the president of Inner Mongolia Academy of Pasture and Agriculture, also participated in the national seminar. They represented the local authority decision-makers in Inner Mongolia and CAS. Mr Duan Ziyuan, the deputy director of Agriculture Office of CAS, who is in charge of cooperation project of CAS in agriculture and grassland areas, came to listen to the report made by Prof. Jiang Gaoming who represented the SUMAMAD Hunshandake project team. The main discussion points were:

- The importance of establishing an Eco-husbandry Special Region in Hunshandake Sandland
- The economic and ecological benefits of replacing middle and large-sized mammals with poultry in the grassland.

Figure 13.
National seminar held in Hohhot, the capital of Inner Mongolia, with the main topic of establishing the largest eco-husbandry special demonstration region in China.
© Prof. Jiang Gaoming

- The possibilities and approaches to increasing the productivity of grassland in order to support more people and releasing pressure from China's huge population.
- Organic food production and marketing in Inner Mongolia grassland, especially in Hunshandake Sandland.
- The potential of carbon sequestration and biodiversity conservation in China's sandlands if well restored.

2012

The national seminar was held in Hohhot, the capital of Inner Mongolia Autonomous Region during 3–5 March 2012 (Fig. 13). The delegates were from the Chinese Academy of Sciences, the Chinese Agriculture Academy of Sciences, China Agriculture University, Lanzhou University, Inner Mongolia University and Inner Mongolia Agriculture University. The main topic of discussion was the scientific bases for establishing the largest Eco-husbandry Special Region in Inner Mongolia to enhance the sustainable development of the region's economy and society. Well known scientists, including three academicians specializing in grassland research in China and ecology studies, attended the national seminar. The main issues of the national seminar included:

- The feasibility of establishing the Eco-husbandry Industry Demonstration Region: opportunities and challenges.
- Utilization and conservation towards sustainable livelihoods in semi-arid grassland areas.
- The application of sustainability science on sandland conservation and utilization in China.

8. Publications as a result of SUMAMAD

Feng, Lifei. 2012. Controlling the dust storm needs a strictly scientific design. *Science News*, October 23, section A, p. 1. [Interview with Jiang Gaoming]

Huang, Chengliang. 2010. Hunshandake Sandland case. In: *Concise Environmental Education Text for Ecological Civilization*. China Environment Press, Beijing, Xiii + 339, pp. 214–217 [in Chinese].

Jiang, Gaoming, Liu Meizh. 2012. Hunshandake Sand area/Xilin Gol Biosphere Reserve in China. In: *Sustainable Management of Marginal Drylands (SUMAMAD) (Phase 2)*. Annual Report 2011, UNESCO, Paris.

Jiang, Gaoming. 2009. Main interests from raising chicken in the steppe. *China Business News*. 13 July, section A, p. 15 [in Chinese].

Jiang, Gaoming. 2009. Storing carbon in the field. *China dialogue*, Febuary 25.

Jiang, Gaoming. 2010. Ecological restoration must respect the natural selection. *China Environment Times*, April 30, Side 2.

Jiang, Gaoming. 2010. Why can natural reserves withstand the natural disaster? *Science Times*, July 23, Side 3.

Jiang, Gaoming. 2012. Restoring eco-balance. *China dialogue* (London), April 13. http://www.chinadialogue.net/article/show/single/en/5028-Restoring-eco-balance

Li, Gang, Liu Meizhen, Li Yonggeng, Jiang Gaoming. 2011. Biomass carbon storage and net primary production in different habitats of Hunshandake Sandland, China. *Acta Ecologica Sinica*, Vol. 31, No.5, pp. 217–224.

Li, Hainan. 2012. A wise choice of returning cropland to woodland in semi-arid areas. *China Business News*. September 20. [Interview with Jiang Gaoming]

Li, Pengfei. 2012. Scientists must tell the truth about ecological construction. *Dazhong Daily*, August 18. [Story of Jiang Gaoming]

Liu, Meizhen, Jiang Gaoming, Yu Shunli, Li Yonggeng, Li Gang. 2009. The role of soil seed bank in natural restoration of the degraded Hunshandake Sandland, North China. *Restoration Ecology*, Vol. 17, No. 1, pp. 127–136.

Meizhen, Liu, Bingxue, Wang, Colin Osborne, Gaoming Jiang. 2012. Chicken farming in grassland increased the environmental sustainability and livelihood quality. Plos One (to be published).

Pipkin, N, Trent D.D., Hazlett R., Bierman, P. 2010. Arid land, wind, and desertification. In: Pipkin, N *et al*., *Geology and the Environment* (6th edition), Hunshandake Sandland case in pp. 408–409. Australia, Brazil, Japan, Korea, Mexico, Singapore, Spain, United Kingdom, United States, Brooks/Cole Cengage Learning. Xviii+ 574.

Qin, Bin. 2010. Degraded grassland turned into green after ten years enclosure. *Xinjing Daily*, April 6.

Su, Benying. 2012. Study on the feedstuff composition and the impact of free-range chicken farming on community structure and primary productivity of the Sandland ecosystem. Master Thesis, Institute of Botany, Chinese Academy of Sciences.

Su, H,. Li, YG., Lan, ZJ., Xu, H., Liu, W., Wang, BX, Jiang, G. 2009. Leaf-level plasticity of *Salix gordejevii* in fixed dunes compared with lowland in Hunshandake Sandland, North China. *Journal of Plant Research,* Vol.122, pp. 611–622.

Wang, Bingxue and Gaoming, Jiang. 2011. Effect of chicken litter on grassland productivity and environmental quality in a sandland ecosystem. *Acta Ecologica Sinica*, Vol. 31, No. 1, pp. 14–23.

9. References

Akiyama, T., Kawamura K. 2007. Grassland degradation in China: Methods of monitoring, management and restoration. *Grassland Science,* Vol. 53, pp. 1–17.

Jiang, G., Han XG and Wu JG. 2006. Restoration and Management of the Inner Mongolia grassland requires a sustainable strategy. *AMBIO*, Vol. 35, pp. 269–70.

Jiang, G., Liu MZ, Niu SL, Li YG, Peng Y, *et al*. 2011. Ten-year-period demonstration project in Hunshandake Sandland and prospect for the future development of eco-stock farming industry. *Science and Technology Review*, Vol. 29, pp. 19–25.

Jing, D. 2002. Sandstorms in Beijing-occurrence, protection and control. Department of Land Water Resources Engineering, Royal Institute of Technology (KTH). MSc. Thesis. Supervisor, Jan-Erik Gustafsson.

Kawamura, K, Akiyama T, Yokota H, Tsutsumi M, Yasuda T. 2005. Comparing MODIS vegetation indices with AVHRR NDVI for monitoring the forage quantity and quality in Inner Mongolia grassland, China. *Grassland Science,* Vol. 51, pp. 33–40.

Li, G., Jiang GM., Li, YG., Liu, MZ, Peng, Y., *et al*. 2007. A new approach to the fight against desertification in Inner Mongolia. *Environmental Conservation,* Vol. 34, pp. 95–97.

Li, G., M.Z. Liu, Y.G. Li, G.M. Jiang. 2011. Biomass carbon storage and net primary production in different habitats of Hunshandake Sandland, China. *Acta Ecologica Sinica*, Vol, 31, pp. 217–224.

Li, WJ., Zhang, Q. 2009. Reading Puzzledom of Grassland-Recognizing the Questions of Management and Utilization of Arid and Semi-arid Grassland. Economic Sciences Press, Beijing [in Chinese].

Liu, MZ., Wang, BX., Osborne, P.C., Jiang, GM. 2013. Chicken farming in grassland increases environmental sustainability and economic efficiency. Plos One (published online).

Liu, MZ., Jiang, GM., Li, G., Li, YG., Gao, LM., Niu, SL. 2004. Control of sandstorms in Inner Mongolia, China. *Environmental Conservation*, Vol. 31, pp. 269–273.

Liu, MZ., Jiang, GM., Yu, SL., Li, YG., Li, G. 2009. The role of soil seed banks in natural restoration of the degraded Hunshandake Sandlands, Northern China. *Restoration Ecology,* Vol. 17, pp. 127–136.

National Environmental Protection General Agency. 2005. China Environmental Condition Bulletin, [in Chinese]. Accessed 23 April: www.zhb.gov.cn

Normile, D. 2007. Getting at the roots of killer dust storms. *Science*, Vol. 317, pp. 314–316.

Pipkin, N., Trent, D.D., Hazlett, R., Bierman, P. 2010. Arid land, wind, and desertification. In Pipkin N *et al.*, Geology and the Environment (6th edition) (Hunshandake Sandland case, pp. 408–409). Australia, Brazil, Japan, Korea, Mexico, Singapore, Spain, United Kingdom, United States: Brooks/ Cole Cengage Learning. Xviii+ 574.

Wang,BX., Jiang, G. 2011. Effect of chicken litter on grassland productivity and environemental quality in a sandland ecosystem. *Acta Ecologica Sinica*, Vol. 31, pp. 14–23.

Wang, G, Dong Z, Zhang J, Liu L. 2004. Modern dust storms in China: an overview. *Journal of Arid Environments,* Vol. 58, pp. 559–574.

Wuyun, TN, Li YL, Jiang GM, Li Y, Wu GL, et al. 2010. Comparison of productivities between chicken corn wheat organic pattern and corn wheat conventional pattern: a case study from Hongyi organic farm. *Journal of Agricultural of University of Hebei*, Vol. 33, pp. 10–16.

Yang, X., Zhang. K., Jia, B., Ci, L. 2005. Desertification assessment in China: An overview. *Journal of Arid Environments,* Vol. 63, pp. 517–531.

Omayed Biosphere Reserve

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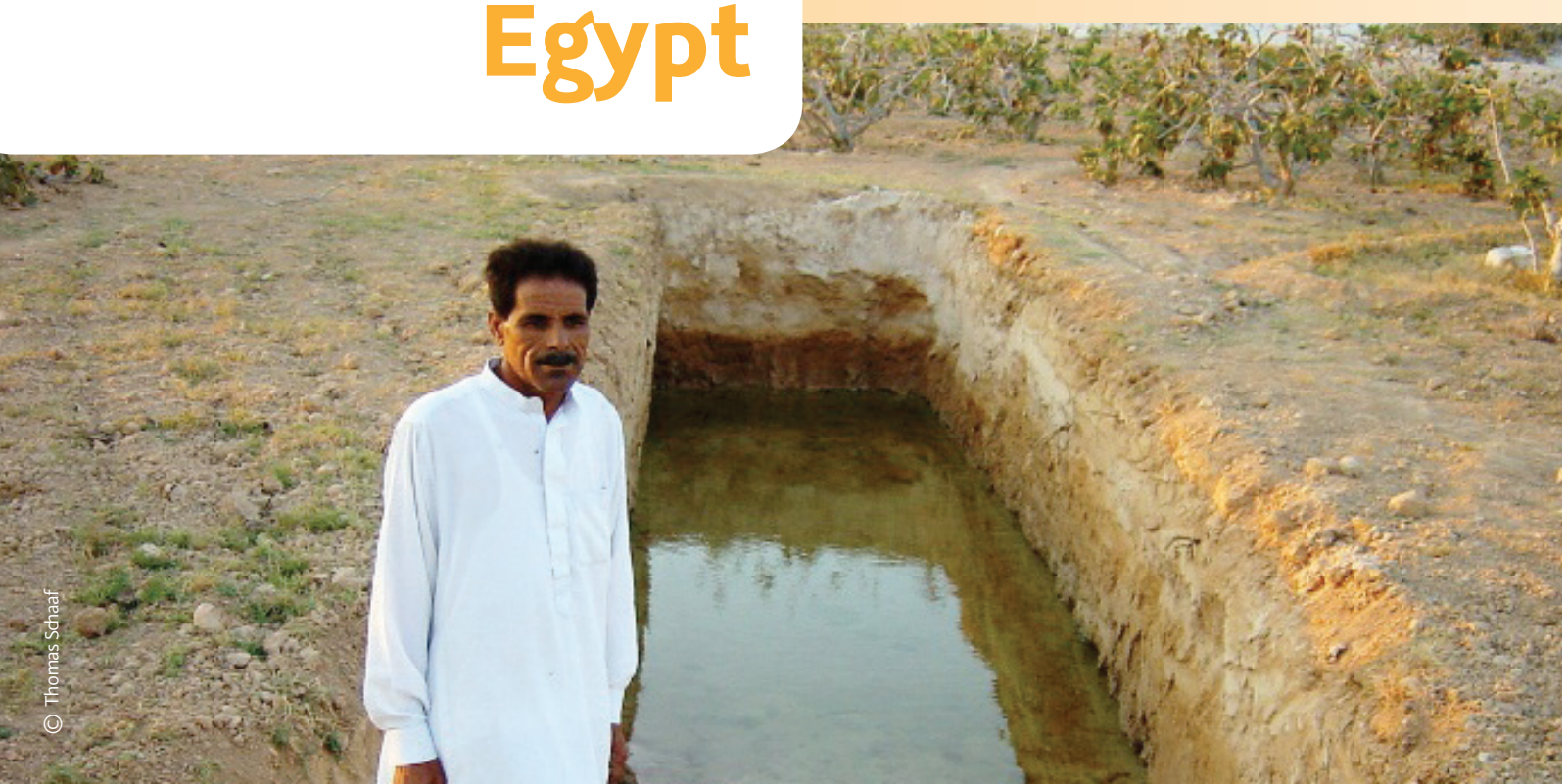

Executive summary

The misuse of natural resources and its negative effect on the environment and sustainable development is one of the most serious problems of the modern world. It is conceivable that issues of environmental conservation and development cannot be dealt with independently, since development cannot rely on a fragile source of environmental resources, while environmental conservation cannot be achieved if development disregards environmental costs. This intimate relationship between environmental conservation and development led to the concept of sustainable development and now provides decision-makers with guidance in many parts of the world in formulating development policies that satisfy the immediate needs of the population without undermining future needs.

Omayed biosphere reserve (OBR) is the Egyptian site in Phase I of the SUMAMAD project, which is part of the World Network of Biosphere Reserves. Covering a total area of 75,800 ha and with elevations ranging from 0 to 110 m, the site was designated as a biosphere reserve in 1981 and extended in 1998. The main objective in the establishment of the OBR was to achieve sustainable development, and to seek better livelihoods for the local communities. Phase II was a continuation of some activities from the first phase of the SUMAMAD project, together with new planned activities that are based on the results, conclusions and lessons learned from the first phase.

The biosphere reserve is located in a warm desert and semi-desert ecosystem with a variety of habitats, including the coastal calcareous dunes consisting of the following dominant plant species: *Ammophila arenaria*, *Euphorbia paralias*, *Pancratium maritimum* eand, and so on; inland ridges with skeletal shallow soils characterized by either *Thymelaea* spp. and *Gymnocarpos decandrum* communities or by associations of *Plantago albicans* and *Asphodelus microcarpus*; saline marshy depressions dominated by *Salicornia fruticosa*, *Cressa cretica*, *Atriplex halimus,* and so on; non-saline depressions and inland plateau, including species such as *Artemisia monosperma* and *Hammada elegans* associations (calcareous soils), *Anabasis articulata* and *Hammada scorpia* (shallow degraded soils) and *Suaeda pruinosa* and *Salsola tetrandra* communities (saline soils); and pasture land, fig plantations and agroecosystems.

1. Achievements and lessons learned from Phase I of SUMAMAD

Through SUMAMAD the Egyptian team was able to achieve the following:

- A complete Geodatabase of OBR based on a participatory GIS approach. Through this database rational management practices could be identified and allocated for the benefit of the local community.
- For the first time, the completion of an ecological study of the natural resources of Moghra Oasis at the hinterland of OBR. This study will contribute towards its nomination to extend the OBR.
- Fresh drinking water was provided to a small community in OBR. This community represents some of the poorest families with no access to fresh drinking water.
- Limited access to credit that made it possible for women to carry out income-generating activities such that women can now earn a living through sewing.

- Identity cards were issued to at least 150 women of the Bedouin community so that they now benefit from rights in terms of inheritance, legal marriages, health, and other services provided by the local government.

- The creation of an NGO comprised of graduate students in environmental sciences that joined the SUMAMAD team and volunteered in awareness-raising workshops held for the local community.

- Successful fund-raising by the NGO to carry out more environmental work at the SUMAMAD site in order to provide fresh drinking water to the local community after showcasing SUMAMAD.

- Remote sensing training of a PhD student who is a member of the SUMAMAD team, as well as an MSc scholarship on the drylands awarded to another member of the SUMAMAD team.

2. Summary of Phase II activities

Phase I of SUMAMAD identified the environmental constraints as the loss of biodiversity, habitat loss and fragmentation, and land degradation. In addition, the over-pumping of water continues, affecting the quality and quantity of groundwater due to a lack of natural discharge. The land transformation currently taking place in OBR is greatly affecting the physical and biological properties of habitats, and is thus increasing pressure on the fragile dry soils. This situation will lead to increased desertification rates, the depletion of resources, soil erosion and loss of productivity. The situation was also exacerbated with expected droughts and water stress, as well as limited productivity due to the impacts of climate change. In this context, it was important in Phase II to assess the nature and scale of the environmental changes and its impacts on ecosystem services.

In addition to the above mentioned situation, the habitats of OBR are undergoing a serious process of transformation from natural rangelands to agricultural lands, particularly as a result of the extension of an irrigation canal and extended irrigation networks from the Nile. The availability of irrigation water has impacted on the lifestyle of the local community and has created conflicts in land tenure due to the increase in land prices. Land tenure is determined by ancestral heritage from the local community, where each tribe and, according to the local Bedouin law (Urf), knows its land property in terms of location and size, and has full control over it. Investors who are newcomers who wish to buy land for cultivation purposes first have to buy the land from the owner of the local community and then pay taxes per metre squared, according to government law. The availability of irrigation water has created interest and attracted many investors to the area, constituting a new type of stakeholder.

The economic constraints in OBR identified in Phase I include:

- Absence of a permanent source of income (revenue).
- Lack of skills.
- Major activities are seasonal (agriculture and grazing).
- Spread of unemployment and thus poverty.

Within a few years, this has changed to:

- Continuous source of income, but to those who own large parcels of land.
- Development of skills, particularly in new irrigation practices.

- Agriculture is an all year round process, however grazing is still seasonal but is receding.
- Unemployment is still a constraint in the poorest sector of the local community.

Land transformation and the change of livelihoods currently taking place in OBR has greatly influenced the lifestyle of the community, increasing conflicts and having immense impacts on the natural resources and natural habitats of the area. This situation calls for urgent assessments, valuation and management intervention towards sustainability, particularly with looming droughts, water stresses due to climate change, and the encroachment of desertification.

Changes in land cover and land use on the one hand drives climate change, while on the other hand are directly or indirectly affected by climate change. The conversion of rangelands into agricultural land for example, drives climate change. It leads to changes in the surface properties of an ecosystem (e.g. albedo, roughness length), as well as the efficiency of the ecosystem to exchange water, energy and CO_2 with the atmosphere. It is expected that the land use shift to agricultural land will continue in the future, making it important to assess factors that are thought to have a direct influence on the social and biophysical vulnerability of traditional and indigenous communities to global climate change. This therefore calls for the continuous monitoring of changes in land use and land cover using remote sensing techniques so as to assess transformed habitats and their value.

The satellite imagery used are:

- Spot5 of 10m resolution image dated June 2009.
- Landsat Thematic Mapper (TM) of 30m resolution image dated 2001.
- Landsat TM of 30m resolution image dated November 1984.

The three images were downloaded onto the computer workspace and subsets of OBR were extracted to carry out analysis of the satellite images. The subsets produced covers almost the entire OBR area of 1427 km² (i.e. 1% = 14.27km²).

The results of the full analysis showed that 7 main land cover classes could be identified from the three satellite images. The differences in the area that had changed during the period between 1984 and 2009 has been estimated and provided in Figure 1.

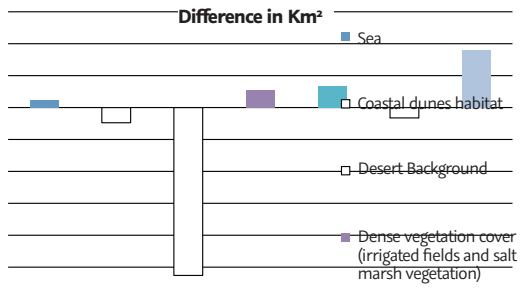

Figure 1.
Difference in area (in km²) of land cover clases in Omayed Biosphere Reserve the period between 1984 and 2009.
© Boshra Salem

The three important results that emerged from this analysis are:

- About 24 km² of habitat of coastal sand dunes has been converted in the development of a summer resort.
- A new land cover class of irrigated cultivation emerged around 2001 with a tremendous increase up until 2009. This land cover class is expected to increase further over the coming years with extensions mainly in the non-saline depression where the new irrigated canal from the Nile is newly extended.
- Rangelands have decreased in area as a result of land degradation and habitat fragmentation due to human interventions.

Further to this, it was important to assess the ecosystem services of the transformed habitats in OBR, which are indicated in Table 1.

TABLE 1.
ECOSYSTEM SERVICES OF THE TRANSFORMED HABITATS

Service type	Service/ good produced	Type of product	Habitat
Provisional services	Food and fibre	i.e. cereal and legumes, rangelands	Non-saline depression
	Fuel wood	i.e. shrubs and sub-shrubs	Ridges, non-saline depression
	Biochemical	i.e. medicinal plants	All habitats
	Freshwater	Groundwater	Non-saline depressions and inland plateau
Regulating services	Water regulation	i.e. determines allocation of rainfall, soil moisture, location of Roman cisterns	All habitats
	Climate regulation	i.e. surface reflectance, carbon sequ-estration, evapo-transpiration	All habitats
	Nutrient cycling	i.e. soil development and primary production	All habitats
Cultural services	Cultural diversity	Creation of unique inspired cultural ecosystems. e.g. nomadic culture, heritage values, traditional knowledge	Rural areas (4 villages)
Spiritual services	Recreation and tourism	Summer resorts protected areas desert safaris	Coastal dunes and their slopes

Activity: Valuation of groundwater lenticels on the coastal dunes of OBR

Purpose: Assessing natural recharge of groundwater lenticels according to current precipitation to estimate the sustainable water abstraction.

The El-Omayed Biospere Reserve receives most of its rainfall in winter, about 151.8 mm/year accounting for 106.26´ 106 m^3 of water. The catchment receives a rainfall volume of about 140.415 ´ 106 m^3, which contributes to water resources within the catchment. About 98 per cent of this volume recharges the groundwater aquifer system during heavy storms, while 2 per cent returns to the atmosphere via evapotranspiration. The average recorded value of pitch evaporation reaches 1,730 mm/year and potential evapotranspiration reaches 1,215.2 mm/ year. The recorded maximum relative humidity varies from 73% to 63% (in July and March, respectively). The study area is characterized by a short rainy season (November-February) with December being the rainiest month (32 mm). The maximum annual rainfall was recorded in the 1989/1990 season (275 mm), while the annual mean value is 152 mm.

The assessment on the natural recharge of groundwater lenticels was carried out by measuring the infiltration rate in sandy and sandy loam soil textures using a double ring infiltrometer consisting of two concentric rings. The rate of fall of water was measured in the inner ring, while a pool of water was maintained at approximately the same level in the outer ring so as to reduce the amount of lateral flow from the inner ring. Generally, the water level was kept at or above 50 mm depth; the difference in height between the inner and outer rings was kept to a minimum. Rain records for the winter season 2013 used to assess the amount of rainwater that could percolate into the groundwater lenticels are ongoing in the field. The level of groundwater was measured at the beginning of the season, as well as

the infiltration rates of the sandy soil of the dunes. A final measure of the groundwater level was taken at the end of the season to determine the amount of natural recharge.

The accumulations of dune sand belong to the Holocene age (Said, 1962). This hydrogeologic matter consists of unconsolidated calcareous sand of high porosity. Such accumulations act as good local reservoirs for direct precipitated rainfall along the coast. Such formations are tapped by a number of wells to yield water of low salinity (ultra freshwater). Surface runoff occurs in the form of flash floods through numerous wadis bisecting the tableland plateau to the south of the coastal plain.

The digital elevation model (DEM) files represent the land surface as a matrix (grid) of elevation values at a given space (resolution 1 arc-second) apart. Free downloads for these DEM files in addition to land use, soil textural classification and image data are made available from http://www.emrl.byu.edu/gsda DEM data is used in Web Map Service (WMS) to automatically delineate basin boundaries and define stream networks. The United States Department of Agriculture (USDA) programme TOPAZ (Garbrecht, and Martz, 1993) is launched from WMS to define flow directions and flow accumulations for each DEM cell. This information is used to trace and convert the stream networks and basin boundaries to lines and polygons of the WMS drainage coverage (Nelson *et al.*, 2000). The polygon and stream network shown in Figure 2 were delineated in WMS using this method.

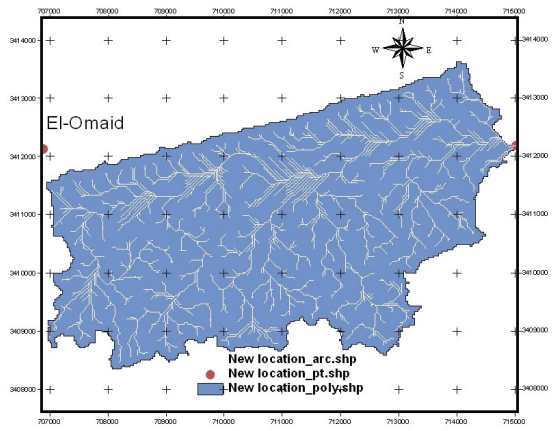

Figure 2.
An automatically delineated watershed boundary created through the use of a digital elevation file and the programme TOPAZ. The streams shown were also automatically created by WMS. © Boshra Salem

The drainage characteristics of terrain surfaces of the present basins required for surface water runoff assessment are automatically computed by applying WMS. These parameters include basin area (A), basin slope (BS), average overland flow (AOFD), and mean basin elevation (AVEL), maximum flow slope (MFS), and maximum stream length (MSL) (Table 2).

TABLE 2.
DRAINAGE CHARACTERISTICS OF TERRAIN SURFACES OF THE EL-OMAYED SUB-BASINS

Drainage characteristics	Symbol	Unit	Value
Sub-basin area	A	km^2	9.45
Sub-basin slope	BS	m/m	0.0295
Average overland flow	AOFD	m	80.41
Mean basin elevation	AVEL	m	12.29
Max flow slope	MFS	m/m	0.0033
Max stream length	MSL	m	6732.24

The measurements were used in the Curve Number method for runoff volume estimation and is expressed mathematically as follows:

$Q = (P - Ia)2 / (P + 0.8 S)$ for $P > 0.2 S$ 1

$Ia = 0.2 S$ 2

A dimensionless curve number CN is defined such as 0<CN>100

$S = (25400 / CN) - 254$ 3

Where P is the accumulated depth of storm rainfall (L), Ia is the initial abstraction (L), and S is the depth of potential abstraction (L). The curve number (CN) is determined according to the type of soil and the weighted CN for mixed land uses and can be computed as follows:

$$CN = \frac{\sum_{i=1}^{K} AiCNi}{\sum_{i=1}^{K} Ai} \quad \ldots\ldots 4$$

Where CNi corresponds to the appropriate CN for the part of the watershed that has an area Ai. Based on equation (4), the curve number of the studied sub-basins was estimated.

TABLE 3.
RUNOFF CURVE NUMBERS FOR SELECTED LAND USES WITH DIFFERENT HYDROLOGIC SOIL GROUP DELINEATION DEFINED FROM LANDSAT INVESTIGATIONS (Ragan and Jackson, 1980; SCS, 1982)

Land use description	Land use description symbol	Texture of the hydrologic soil group			
		A	B	C	D
Cultivated land (dense range)	LS1	62	71	88	81
Pasture (poor condition)	LS2	68	79	86	89
Pasture (good condition)	LS3	39	61	74	80
Rocks, streets, roads	LS4	98	98	98	98
Infiltration rate of the hydrologic soil group k (m/day)	k > 6	1.5 < k ≤6	0.1<k≤1.5	k < 0.1	

A = sand, loamy and sandy loam; B = silt loam and loam; C = sandy clay loam; D = clay loam, silty clay loam, silty clay and clay

The percentage of the different land use of the studied sub-basin (with a total area of 9.45 km²) was estimated from the landsat images. The sum of the products of these percentages by their coefficients, shown in Table 3, gives CN value, while the general relationship between rainfall and runoff is estimated.

Using equation (4), and after substituting the CN value according to C group, the weighted curve number for the studied sub-basin is:

$CN = (0.05)*(9.45)*(0.88) + (0.95)*(9.45)*(0.86) / 9.45 = 86.1$

Then using equation (3) to determine the maximum potential retention (S) gives:

$S = (25400/86.1) - 254 = 41$ mm

Accordingly, the initial abstraction (Ia) and the potential maximum retention (S) are equal to 8.2 mm and 41 mm respectively.

So the relationship between rainfall and runoff is given by:

$$Q_= (P - 8.2)2 / (P + 41) \qquad \text{for } P > 0.2\ S \text{.....5}$$

From the SCS curve number model, it is clear from equation 5 that there is an inverse relationship between the estimated value of CN and Ia of the studied sub-basins. The mean value of CN for the studied sub-basin (86.1) is close to the estimated value of CN value of the basins of Umm El Rakham coastal area, which is 80.5 (Gad *et al.*, 2002). Otherwise, the high estimated value of Ia (8.2 mm) may be attributed to the high infiltration rate of the sand sheets and the effect of the lithologic control of this sub-basin (natural sand dunes vegetation, which is sparse with less than 5% cover with a high infiltration rate of 1.4 m/day). Furthermore, the average runoff depth produced by a rainfall shower of 25 mm reaches 4.28 mm, while the runoff coefficient reaches 17%, which is comparable with the runoff coefficient of the northwestern coastal zone area (Gad, 2009).

Accordingly, the studied sub-basin receives about 213,625 m^3 from storm rainfall during the 1994/95 season as surface runoff volume. Assuming that this quantity is the average annual runoff volume over the study area, every square kilometre of the studied catchment received 17,467.29 m^3/year, since the area of the catchment comprises 9.45 km^2. This means that every feddan[1] had lost 73.363 m^3, although fresh groundwater resources are scarce. Thus, good management in water harvesting (WH) is an important requirement.

1 An Egyptian unit of area equivalent to 1.038 acres (0.42 ha).

3. Improvement of dryland agriculture and rehabilitation of degraded ecosystems

3.1 Dryland agriculture: fostering scientific drylands research

Assessing the use of vegetation Gel Nutrition Media (GNM) on threatened species of OBR.

The GNM is an agar-based material enriched with nutrients. It is composed of the following solid materials: agar powder (10 gm), 2.5 gm of nutrients (NPK of equal ratios), 30 gm sucrose. These solid materials are dissolved in 1000 ml of water and boiled on a hot plate until complete solubility and the formation of the gel. The pH of this mixture is 5.8. The agar was chosen because of its known ability to form a net polymer that saves water and nutrients, and makes them available to plants when placed at the root zone.

Purpose of the experiment: To enhance the productivity of annual crops grown in the desert in degraded soil.

Method: The GNM was prepared in the Biotechnology Lab of the Faculty of Agriculture, University of Alexandria, according to a patent owned by one of its staff members. An experiment was designed to apply the GNM on varieties of barley and wheat seeds brought from the Omayed site. The seeds were sown in the field after mixing with the GNM and, for comparison, in pots in the lab using the same soil type.

Results: Field and lab observations showed that seeds sown in the field and lab using the GNM have

more successful germination percentages, longer seedlings, and enhanced growth rates. Figure 3 shows the results obtained from the lab.

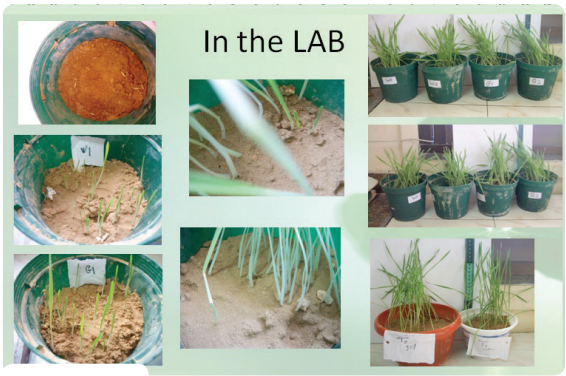

Figure 3a.

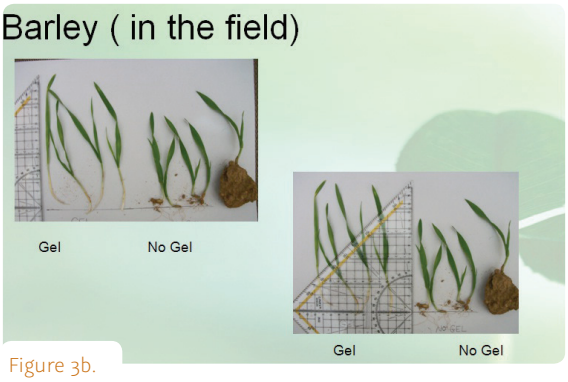

Figure 3b.
Assessing the use of vegetation Gel Nutrition Media (GNM) on threatened species of OBR. © Boshra Salem

The results obtained from the field show the same results, where there has been a significant growth in terms of the length and width of the leaf blade. The results indicated that normal fertilizers cost / feddan = L.E. 260 (~ US$ 37). The GMN cost / feddan is L.E. 190 (~ US$ 27). This proves that the GMN demonstrates better productivity with less water and at less cost.

3.2 Recent irrigated agriculture in OBR

Since the extension of the El Hammam canal brought the Nile to OBR, nine major types of agricultural crops are grown in OBR. The crops have a significant economic return and represent a source of income for the local community. These are peach, figs, olives, grapes, apple, pear, melon, tomato and barley, covering a total area of 22,650 acres on both banks of El Hammam canal with a breadth of about 1 km in both directions. Most landholders are investors from the land reclamation sector. All the surrounding lands are owned by local villagers from El Omayed village, Sahel El Omayed, El Shammama village and Awlad Gebriel village. Eight thousand people live in these four villages, with agriculture their main income source. The main plants species cultivated in the rainfed areas are fig trees, olive trees, as well as barley and watermelons. The estimated combined annual yield of these crops is 101,150,000 pounds. SUMAMAD has provided local farmers with high yielding multipurpose olive propagules. These olives types were irrigated using modern irrigation methods, which is compatible with the natural conditions of the region, the climatic characteristics and soil qualities.

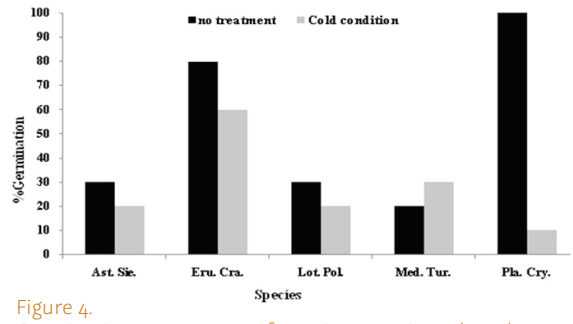

Figure 4.
Germination percentage of species germinated under no treatment and cold conditions. © Boshra Salem

3.3 Rehabilitation of degraded ecosystems

The achievement of objectives of this activity was expected in two stages. The first stage involved the field surveys for specimens and seed collection together with the germination trials. The second stage involved the propagation trials of the most promising species based on the results obtained from the first phase. Both phases were associated with intensive field visits to survey the natural plant resources of OBR and to assess their uses and provide the basis for their conservation, together with collecting plant and seed samples from the different ecosystems in the area.

During the field visits, seeds were collected from the plants, directly identified, and tested. Samples from the recorded species were collected and prepared as herbarium sheets for identification. The collected seeds were prepared for subsequent germination and propagation trials. Floristic identifications, based on Täckholm (1974), together with the Latin names of the species were updated following Boulos (1995, 1999, 2000, 2002, 2005). Through field collection a total of 37 species were collected, representing the different range of ecosystems and habitats in the study area of which 15 species are perennial shrubs, while the rest are annual herbs. These species belong to 28 genera and 10 families. More than 62 per cent of these species belongs to Leguminosae, Compositae and Cruciferae families, members of these families are known to have a wide distribution in the Egyptian desert. The rest of the species belong to Alliaceae, Labiatae, Malvaceae, Plantaginaceae, Umbelliferae, Zygophyllaceae and Papaveraceae families.

Seeds of the same species were germinated in petri dishes in two sets. One set was not subjected to any treatment, where 10 seeds of each species were placed in petri dishes on filter paper moistened with water and then left at room temperature. Water was added when necessary to keep the filter paper moist during the period of the experiment. The other set of seeds was subjected to cold condition, where 10 seeds of each species were placed in petri dishes on filter paper moistened with water and then left under cold conditions at 4°C. Germination was observed for a period of 20 days and the germination percentage was subsequently calculated for each species. About 43% of the studied species germinated under no treatment, while about 24% of the studied species germinated under cold conditions. This suggests that the future germination and propagation trials will not be carried out under cold conditions. Generally, species germinated under no treatment showed a higher percentage of germination than those germinated under cold conditions (Fig. 4).

A germination percentage of more than 50% was attained by 16% of the studied species under no treatment (*Astragalus sieberi*, *Brassica tournefortii*, *Erucaria crassifolia*, *Plantago crypsoides*, *Salvia Lanigera* and *Vicia monantha*). The highest germination percentage reported under cold conditions was attained by *Erucaria crassifolia*. Five of the studied species germinated under both conditions (Fig. 9). These species include *Astragalus sieberi*, *Erucaria crassifolia*, *Lotus polyphyllos*, *Medicago turbinata* and *Plantago crypsoides*. It is worth noting that these species attained higher germination rates under no treatment than that under cold conditions.

4. Scenarios for future land use changes under climate changes

4.1 Climate change

With regard to climate change data, and according to the data from the IPCC Technical Paper V (2002),

the annual temperature trends for the period 1901 to 2000 has increased in Egypt by 0.2°C, while annual precipitation has decreased by 30%. The recorded temperatures and precipitation in the study area from 1950 to 2001 were collected and analysed. The results showed that the trend in maximum temperature did not show a significant increase, except in the last few years where it shows a very slight increase but does

TABLE 5.
MITIGATION AND ADAPTATION TO CLIMATE CHANGE IN OBR

Mitigation	Adaptation
Reducing net greenhouse gas emissions to the atmosphere and enhancing the sinks of greenhouse gases through (a) conservation of existing carbon pools, i.e., avoiding deforestation (b) sequestration by increasing the size of carbon pools, i.e. through propagation of native species, and (c) substitution of fossil fuel energy in the surrounding industrial and urban sector by use of modern biomass.	Implementing activities that reduce a system's human vulnerability to climate change.
Plantations of native tree species to support biodiversity rather than more exotic species, as well as plantations of mixed tree species to support more biodiversity than monocultures.	Plantations are to be designed to allow for the colonization and establishment of diverse understory plant communities by providing shade and by ameliorating microclimates, providing canopy gaps, retaining some dead wood components, and providing landscape connectivity.
Applying agricultural management activities (i.e. conservation tillage, erosion control practices and irrigation) that will sequester carbon in soils.	Adapting to the use of erosion control practices, including water conservation structures, vegetative strips, and shelterbelts for wind erosion control to reduce the displacement of soil organic carbon and provide opportunities to increase biodiversity.
Include community participatory approaches and the consideration of local or indigenous knowledge and technologies.	Promote recycling and use of organic materials in low-input farming systems, and use a diverse array of locally adapted crop varieties.
Improved management of rangelands through propagation of nitrogen-fixing legumes and high-productivity native grasses.	Application of grazing rotational schemes.
Promote rehabilitation activities that increase plant cover on eroded, severely degraded, or otherwise disturbed lands.	Match the plant species to the site conditions and consider which key ecological functions need to be restored.
Reduction of other pressures on biodiversity arising from habitat conversion, over-harvesting, pollution and alien species invasions.	Counter habitat fragmentation through the establishment of biological corridors and maintenance of ecosystem structure and function, and the conservation of ecotones as repositories of genetic diversity. This might include conventional collection and storage in gene banks as well as dynamic management of populations, allowing continued adaptation to changing conditions through evolution.
Protection, restoration or establishment of biologically diverse ecosystems that provide important goods and services that may constitute important adaptation measures to supplement existing goods and services, in anticipation of increased pressures or demand, or to compensate for likely losses.	

not exceed the 0.2°C. These results are consistent with the results of the *IPCC Fourth Assessment Report: Climate Change 2007* (AR4). With regard to precipitation, the late 1970s (1978 and 1979), and the year 2000 recorded the highest relative precipitation since the 1950s. In arid and semi-arid regions like OBR, the rainy seasons directly reflect the amount of annual natural vegetation cover.

Mitigation and adaptation measures in OBR: There are significant opportunities for mitigating and adapting to climate change, while enhancing the conservation of biodiversity. In OBR, the following can be recommended (Table 5)

4.2 Stakeholder analysis

In order to develop scenarios, stakeholders need to be identified. The first step in stakeholder analysis is to identify people, groups and organizations who are important in the evaluation or who might be affected by the outcome. Several identification criteria can be used, such as type of influence, people who are affected by the policy resulting from the evaluation, as well as those who affect policy.

Accordingly, stakeholders in OBR can be identified among:

- Local community: members from the poorest sector (mainly rangers), and rich local community members (landowners).
- New rural community of newcomers (farmers).
- Investors in the agriculture sector and the tourism sector.
- Government agencies: local council, Governorate of Matruh, State ministries of environment, agriculture, reclamation and water resources.
- Military sector: frontier army, Ministry of Defence.
- Educational institutions: universities and research centres.

A distinction should be made between stakeholders who identify themselves as a cohesive group (e.g. companies and NGOs), and unorganized groups such as small businesses and households. For OBR, the stakeholder analysis is presented in Figure 5.

This figure shows that there are many players in OBR, such as external stakeholders, who may have positive impacts on the development of the area, yet negative impacts on its ecosystems. Such external stakeholders, particularly investors, have a big influence on the OBR, and the prolonged actions they cause may lead to even further land degradation in the area. It is expected that dividing the OBR into two sectors, as indicated above, is a good way to separate the heavily impacted areas from those that are less impacted.

Management Plan of OBR — Examining Scenarios

The primary aim of this activity is to present a tentative model so as to:

- simulate trends of variation in ecological conditions due to different land uses;
- contribute information to planners; and
- indicate the consequences in the implementation of various scenarios.

In the previous reports, several scenarios were presented for the management of the biosphere reserve. The idea is not to select just one scenario, but rather to combine them when managing the different zones of the OBR. The scenarios are summarized in Table 6 below.

TABLE 6.
MANAGEMENT SCENARIOS IN OBR, THEIR DESCRIPTION AND CONSEQUENCES

Scenario	Description	Consequences
Level 1: Full protection	Proposed only for the comparison of economic values with other scenarios.	Each land unit will evolve according to its regenerative capacity.
Level 2: Rangeland development and limitation of the ploughed fields	Annual crops cultivation and tree plantations would be limited only to suitable areas, adjustment of stocking rate on the ranges to the present grazing capacity.	Rational use of rangelands leads to biological recovery and satisfactory control of degradation.
Level 3: Continuation of present practices and maintenance of present land use system	More ploughing for cropping and extension of orchards and annual cropping of cereal and vegetables, particularly after the extension of the supplementary irrigation canal from the Nile. An increase in the number of animals implies no management planning of rangelands.	Acceleration of the clearing of more attractive areas for ploughing. Decrease of areas used for grazing.
Level 4: Intensification of present practices	Socio-demographic conditions necessitates new extension, investments are made for promoting the use of resources.	All possible misuses of the area accumulate.
Level 5: Extension in land reclamation using the supplementary irrigation canal as a source of irrigation water.	Development must be evaluated according to environmental potentials and the availability of the local labour force.	Heavy investments for introducing such level of intensity of human pressure.

The proposed plan for the management of OBR is to divide it into two sectors: the northern sector, where all the human impacts prevail, i.e. urbanization and extensive agriculture; and the southern sector, with less impact and relatively dense vegetation cover. The two sectors are demonstrated in the Figure 6.

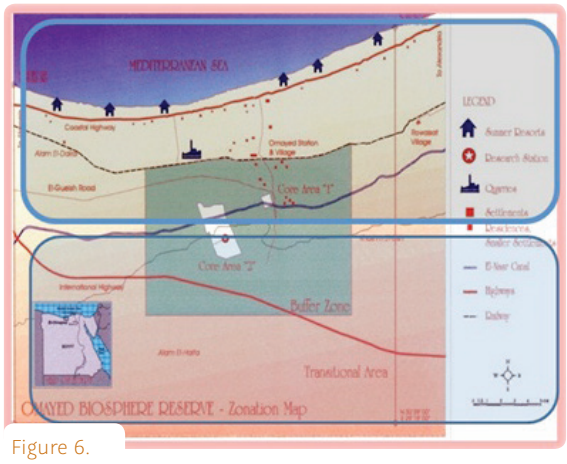

Figure 6.
Location of the Omayed Biosphere Reserve and its structure.
© Boshra Salem

In the northern sector, scenario 1 provides full protection in the existing core area and two more core areas in the coastal dunes and saline depression. Other areas of the northern sector will follow scenarios 3 and 4 where there is more ploughing for cropping and an extension of orchards and annual cropping of cereal and vegetables, particularly after the extension of the supplementary irrigation canal from the Nile. As well as an increase in the number of animals, which implies no rangeland planning or management, and where socio-demographic conditions necessitates new extension, investments are made for promoting the use of resources.

In the mainly rangeland southern sector, scenario 2 will be applied where the cultivation of annual crops and tree plantations are limited to suitable areas, with an adjustment of the stocking rate on the ranges to align with the current grazing capacity. In this sector, two core areas will be established, representing the

flora and fauna of the inland plateau, where scenario 1 will be implemented. It is expected that with such a division, the OBR would develop and thus satisfy the three objectives of a biosphere reserve, according to the Seville Strategy and the Madrid Action Plan.

4.3 Income generating activities

Income-generating activities were implemented in Phase I and II of the SUMAMAD project to meet local community needs for both men and women. Women of the local community were visited several times to check on the Phase I activity, which involved sewing and teaching young girls to sew their own costumes. The activity was still in demand and more women expressed a desire to join. Several other women requested the SUMAMAD team to help provide weaving equipment to produce handicrafts. A local NGO helped in calculating the number and costs of the required equipment and to arrange training for the young women to revive the heritage of handicrafts. The product samples are shown in Figure 7. Other products include small carpets, pillows cases, bags, and so on. It is planned to make use of the nearby market opportunities in the summer resorts.

Figure 7.
Samples of handicrafts produced by women.
© Boshra Salem

TABLE 7.
PLAN FOR WOMEN'S HANDICRAFTS IN AWALD GEBRIEL VILLAGE

Hamlet (community name)	No. of trainees	No. of trainers	Previous experience	No. of women willing to start handicrafting	Cost of activities in L.E/Qintar One Qintar -45 kg)	Total
Mosalam	10	3	7	4	500 pounds/woman for weaving 200 pounds /women for handcrafting of wool	5000+2000=7000
Wareel	10	3	5	2	500 pounds/woman for weaving 200 pounds /women for handcrafting of wool	7000
Abouhessa	12	3	3	5	500 pounds/woman for weaving 200 pounds /women for handcrafting of wool	6000+2400= 8400
Balousa	23	2	19	9	500 pounds/woman for weaving 200 pounds /women for handcrafting of wool	7000
Weheda	9	1	2	-	700 /Qintar/women for weaving 400/women/Qintar handicrafting	4500+1800= 6300
Total						L.E.35700 i.e. about $ 6700

Alternative livelihoods for men were investigated and it was found that providing men with olive tree propagules, with the double purpose of the production of oil and pickles, was the best alternative source of income selected by the locals. The following photos demonstrate a successful example that could be repeated.

Figure 8.
Top: The household of a bedouin family who had olive tree propagules, with the double purpose of the production of oil and pickles. **Bottom:** A sample from pickles production. © Boshra Salem

4.4 Solar water desalination

Ensuring sustainable livelihoods was implemented in Phase II, not only through alternative income-generating activities, but also by improving livelihoods by providing freshwater to the community. In Phase I, a solar desalination still was provided to local communities that suffered from a lack of drinking water facilities. In Phase II, this activity was continued and performed jointly with the Ecosystems and Human Development association (EHDA). More solar desalination units were provided to local communities in Burg El Arab, and El Arish, at the eastern desert of Egypt. Table 8 shows the number of units provided.

TABLE 8.
NUMBER OF SOLAR DESALINATION UNITS PROVIDED TO LOCAL COMMUNITIES

Site	Number of units	Number of people	Phases
Burg El Arab (1) and (2)	10	47	I and II
El Ariesh (1) and (2)	12	53	II
Omayed	8	28	I

Figure 9.
New installations of solar desalination units.
Top: One of the bedouin trained to mantain the solar system on the roof of his house.
Bottom: Children of the same family drinking the desalinated water. © Boshra Salem

4.5 Solar water desalination system

Due to the request from the local community, the SUMAMAD team worked on improving the existing manufactured water desalination solar still so as to achieve a better performance and cost-effectiveness.

The proposed improvement includes:

- Increasing the surface area of the solar still.
- Adding a Concentrated Solar Panel (CSP) to concentrate solar energy.
- Adding a partial brine recycle with the possibility of salt production.

The improved system is presented in Figure 9, and is composed of:

- A sub-system that encloses the inner cylinder, creating an airtight medium.
- A transparent glass box with a flat top (2.5 m x 1.5 m x 1.5 m).
- A transparent box with cylindrical top (2.5 m x 1.5 m x 1.5 m).

4.5.1 Economies of the improved system

The new system produced 650 ml from 1 litre input water in 10 minutes, i.e. approx. 4 litres/hour in autumn/spring, which was equal to 20–22 litres/day in winter and 32–34 litres/day in summer.

4.5.2 Improvement over previous version

V2 area is equal to 1.2 V1 units. Winter improvement 21/(12*1.2) = 145%,

Summer improvement 33/(18*1.2) = 152% and the Average Improvement = 148.5%

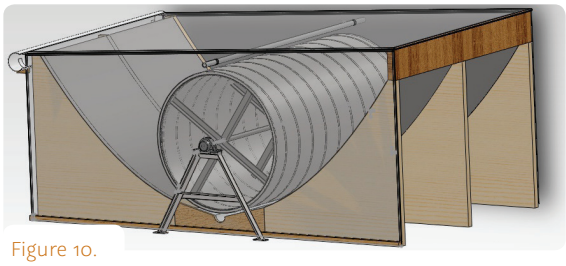

Figure 10.
Improved solar water desalination system. © Boshra Salem

5. Recommendations for the sustainable management of drylands

The national seminar of 2013 concluded with the following recommendations for the sustainable development of marginal drylands.

Maintaining economic security

- Monitoring agrodiversity through the current irrigated cropping system and the integration of livestock and other important edible flora, avoiding monocultures and following a crop rotation system.
- Conservation and efficient utilization of resources with least dependency on external inputs.
- Fairness in production and utilization of resources such that every local stakeholder has rights to share the benefits of the resources.

Maintaining ecological security

- Conservation of biodiversity.
- Rehabilitation of degraded ecosystems by propagation of endangered species.
- Mitigating the effect of climate change.

- Maintaining food chains and ecological balance through the integrated promotion of flora and fauna, and implementing rotational grazing patterns.
- Restoration of soil fertility by conservation efforts.

Running capacity-building and awareness programs

For this activity, SUMAMAD staff prepared policy-relevant guidelines for decision-makers in drylands with the purpose of raising the awareness of local policy-makers on ecosystem services and climate change adaption and mitigation (Arabic documents).

Twelve Arabic documents were prepared for distribution among the local community, containing simplified information on the following:

- Biodiversity
- Biodiversity conservation
- Biodiversity in Arab countries
- Sustainable development
- Droughts
- Desertification
- Land reclamation
- Fertilizers and insecticides
- Agriculture and environmental protection
- Environmental auditing
- Sustainable agriculture
- The values of the tree

6. Research institution and team composition

Partner Institution

Department of Environmental Sciences, Faculty of Science-University of Alexandria in coordination with National UNESCO Commission

Administration Team

Mr. Safwat Salem
General Secretary
National UNESCO Commission

Mr. Mohamed Eisawy
Manager
Omayed Biosphere Reserve

Scientific Team

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Ms Marwa Wassem
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Faculty of Science, University of Alexandria

Ms Marwa Gaber
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Supporting Team

Members of the following NGOs:
Ecosystems and Human Development Association – Alexandria
Local Community Development – Omayed Village

7. List of national workshops

National workshops: A participatory approach 2009–2010

A series of national workshops with stakeholders was organized in the OBR in 2009 and 2010, with more than 50 attendees. The manager of the OBR and his assistants were also among the participants. The aim of the national workshops was to:

- Spread awareness about the role of the biosphere reserve to local people, and the associated problems of environmental degradation.
- Discuss governance mechanisms in terms of general consensus, public participation, and conflict resolution.
- Inform about climate change issues, and preparedness of the local community to combat the anticipated climatic changes.

An Arabic document was prepared for this purpose.

The output of these workshops included:

- Involving locals to understand and discuss the role of the biosphere reserve.
- Involving locals to understand the nature of climate changes and how it will affect their environmental services.
- Reaching a consensus that all stakeholders share the responsibility to find livelihood alternatives to mitigate climate change impacts. In this regard the common priority was to continue the efforts of rehabilitation of the Roman cisterns for rainwater catchments, and the possibility of using the bio-saline resources of the salt marsh vegetation as fodder.

A memorandum of understanding with a local community development organization (a local NGO) to work with the SUMAMAD team and liaise with the local community for maintenance of the rehabilitated cisterns, as well as income-generating activities for women and men. Figure 11 shows the event and the participants involved.

Figure 11.
SUMAMAD workshops and participants. © Boshra Salem

8. List of national seminars

2011

A national workshop was held in Cairo at the Supreme Council of Universities, Environment Committee. The attendees were all environment experts at different universities in Egypt. They have varying expertise in environment, environmental engineering, agriculture, earth sciences, geography, hydrology and others.

Figure 12.
Participants of the national workshop. © Boshra Salem

Members of the committee commended the work of SUMAMAD, and the minutes of the meeting documented the comments and suggestions made by the committee members. It was decided that the work should be extended to cover other areas in Sinai, Upper Egypt, where there are communities in need of such activities and support.

2013

A national seminar was organized at the department of environmental sciences to describe the work done by the SUMAMAD team, and present the published papers. Attendees of this workshop were the staff of the department, and post- and undergraduate students. The manager of OBR attended this workshop and explained the new ongoing activities in OBR and the ways to overcome the obstacles brought about by the new investors. The workshop ended with a discussion on the recommendations for dryland management. The recommendations that emerged from this workshop are presented in the next paragraph.

Figure 13.
Workshop participants in the national seminar in 2013. © Boshra Salem

9. Publications as a result of SUMAMAD

Paper 1 (2013). *ESD as a Means to Strengthen the Sustainable Management of Marginal Drylands in Egypt.* Published in the International Journal of Education for Sustainable Development.

Joint work with a TEMPUS project 'Education Outside the Campus' to produce an educational school kit on biodiversity, water, energy and agriculture.

The Journal of Education for Sustainable Development (JESD) is a forum for academics and practitioners to share and critique innovations in thinking and practice in the emerging field of Education for Sustainable Development (ESD). A peer-reviewed international journal, JESD aims at global readership and is published twice a year. The journal seeks

articles from the fields of environmental education, which pioneered much of the work in ESD, as well as from economics education, social sciences and the humanities.

Paper 2. (2013). *Assessing Sustainability Practices in Marginal Drylands using the Compass Tool. Case Study: Western coastal desert of Egypt.*

This paper is under preparation using the ISIS Academy tools. Details of the paper on the ISIS tools will be provided in the workshop. Such tools will be used to evaluate the sustainability practices carried out in SUMAMAD activities during the two phases.

10. References

Gad, M. I. 2009. A numerical approach for estimating the monthly groundwater recharge from rainfall, Wadi El Khour basin, northwestern coastal zone, Egypt. Egyptian Journal of Aquatic Research, Vol. 35, No. 3, pp. 265-280.

Gad, M. I., Farag, M. H., Zaki, M. H. 2002. Simulation of direct runoff volumes and peak rates for some catchments in El Qasr-Umm El Rakham area, northwestern coastal zone, Egypt. 3rd Regional Conference on Civil Engineering Technology and 3rd International Symposium on Environmental Hydrology Proceeding, 8-10 April 2002 (proceeding in CD).

Garbrecht, J., Martz, L.W. 1993. Comment on 'A combined algorithm for automated drainage network extraction' by Jean Chorowicz *et al*. *Water Resources Research 29*: doi: 10.1029/92WR02428.

Nelson, C. H., Weistrop, D., Hutchings, J. B., Crenshaw, D. M., Gull, T. R., Kaiser, M. E., Kraemer, S. B., Lindler, D. 2000. Space Telescope Imaging Spectrograph Long-Slit Spectroscopy of the Narrow-Line Region of NGC 4151. I. Kinematics and Emission-Line Ratios. *The Astrophysical Journal,* Vol. 531, No. 1, pp. 257-277.

Ragan, R.M. and T.J. Jackson, 1980. Runoff Synthesis Using Landsat and SCS Model, *J. of Hydrology,* Divn., ASCE, Vol. 106 (HYS5), pp. 667-678.

Said . R. 1962. *The Geology of Egypt*. Elsevier, New York. xv + p. 377.

Soil Conservation Service (SCS). 1982 [Draft]. Structure site analysis computer program DAMS2 (interim version). *SCS Technical Release 48*. Washington, DC.

Technological Interventions for the Sustainable Management of Drylands in Western Rajasthan

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1. Location of project sites and some dryland challenges

The principal hot arid western region of India (19.084 million ha) is situated mostly in the western part of Rajasthan state, better known as Thar Desert. The region has an arid climate with erratic behaviour and low rainfall (100-450 mm/ year; ~90% during July-September), extreme temperatures (often >45°C in the peak of summer and sub-zero in winter), and high summer winds (>30 km hr^{-1} during summer), which are the continual climatic problems to deal with, especially for agriculture. Drought is and will remain a major determining factor of agricultural activity in the region. There is a distinct rainfall gradient from east to west, where the mean annual rainfall varies from 100 mm in the westernmost part of Jaisalmer district to 370 mm in the east of Jodhpur; most rainfall is received during the southwest monsoon (July-September), as in other parts of the country.

Project related activities have been implemented in the villages of Bharamsar (Jaisalmer) and Bujawar and Rohila Kalan (Jodhpur) (Fig.1) representing rainfall situations of <200 mm and 200-400 mm, respectively. Bharamsar village is located between 26°58'50" and 27°04'10" N latitudes and 70°50'00" and 70°56'48" E longitudes, and is typical representative of the rural landscape in Jaisalmer district. The area of the village is 13,016 ha, a large part of which is rocky. Dominant soils of the village include Khadin soils (coarse to fine loamy), fine loamy, coarse loamy, duny complex, salt affected soils, shallow gravely soils, and rocky hills and outcrops. All soils are poor in organic carbon (0.04-0.45%), low to medium in available P_2O_5 (4 to 28 kg ha^{-1}) and highly variable in available K_2O (90 to 1277 kg ha^{-1}).

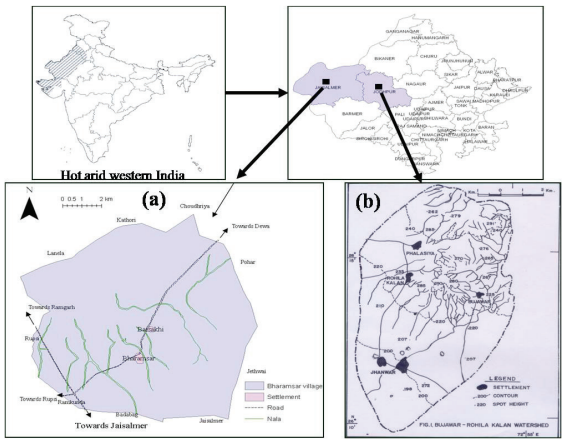

Figure 1.
Hot arid western India and the study location at western Rajasthan: a) Bharamsar village, representing <200 mm rainfall zone (Site II); and b) Bujawar and Rohilla Kalan village, representing 200-400 mm rainfall zone (Site I).

The rocky terrains of Bharamsar village generate about 2.38 mcm runoff (based on 60% probability of 110 mm rainfall), which is stored in *nadis* (village ponds) and Khadins. Of the total area only 13.76% is under cultivation (cropping intensity 20–100%). Wheat, chick pea, mustard (in Khadin), pearl millet, cluster bean are the main crops in these lands. The irrigated area in the village was 2,559 ha. Wastelands and permanent pastures constitute 83% of the area of the village. Both wastelands and permanent pastures serve as open grazing land for more than 2,000 village livestock.

The total human population of Bharamsar village is 2,672 with a male: female ratio of 1:0.86. The total number of households in the village is 433 with an average agricultural land holding of 4.13 ha/ household. Literacy rate in the village is 26.57%

(male: 42.83% and female: 7.88%). Interestingly, the per capita income in this village is Rs. 29,000 per annum (~US$ 530), which is much higher than the project villages of Jodhpur.

The villages of Bujawar and Rohila Kalanare located between 26°10' – 26°16'N latitudes and 72°50' – 72°54'E longitudes, having an area of 1,631 ha and 427 ha, respectively. These villages are located in Luni block in the district of Jodhpur. The soils are coarse loamy with varying degrees of wind and water erosion hazards. These soils have low organic matter (0.06 – 0.13%), low to medium in available phosphorus (8.01 kg ha^{-1}) and medium to high available potassium (101-349 kg ha^{-1}). The land use statistics of the villages revealed 32% of the area as hilly and rocky, 6% permanent pastures and sandy wasteland, 33% arable land, and 30% as fallow. The total dryland area in these villages is 88%. The irrigated area for agriculture in the Bujhawar village was only 26 ha, while in Rohilan Kalan the entire agricultural land was rainfed. The main crops in these two villages were pearl millet, arid legumes, sesame, and so on. The livestock population of these villages is about 4,000 animal heads. Of the total animal population, 16% are cattle and buffalo, 82% sheep and goat, and 2% camel and mules.

Total human population of Bujhawar village is 871 with male: female ratio in the order of 1:0.95. The total number of households in the village is 128 with an agricultural land holding of 2.95 ha/household. The literacy rate in the village is 35.59% (male: 51.12% and female: 19.29%). The per capita income in the village is Rs. 22,500 per annum (~US$ 402). In Rohila Kalan the total population was 2,201 with the male: female ratio in the order of 1:0.96. The total number of households was 257, and agricultural land per household was in the order of 7.90 ha. The literacy rate in the village was 41.67 (male: 41.67% and female:24.14%). Per capita income of the village is Rs. 20,055 per annum (~US$ 366).

In all project villages, mixed crop-livestock farming, mixed livestock-crop farming and livestock farming form the spectrum of economic activities. Trees on the agricultural fields, such as multipurpose species like *Prosopis cineraria*, *Acacia nilotica*, *Acacia senegal*, *Ziziphus* species, and so on, provide a large number of end-use products. In addition to their contribution to food security in difficult times, trees on agriculture fields are an important source of income. Boffa (1999) suggested that multipurpose trees on agricultural fields, in the same situation as in the project villages, are important for rural food security and income generation and, to some extent, ensures social and cultural stability. In fact, the rural population of the Thar Desert has been practicing arable cropping and animal husbandry in association with scattered trees in agricultural fields since time immemorial and as such combined proactive-productive systems of integration of trees into farming systems is rooted in the principles of ecological economics, productivity and sustainability (Narain and Tewari, 2001).

The complex web of socioeconomic and cultural conditions in the project villages, coupled with the low income and the low literacy rate, especially among women, are major causes in the failure of development to reach expected levels, despite the substantial support from central and state government. Moreover, environmentally disadvantaged situations with low and erratic rainfall, severe wind and water erosion, and recurring droughts have a highly negative impact on the agriculture based economy of the project villages. Livestock are the very basis of existence in the project villages and contribute substantially to the economy. Traditional practices of animal husbandry are based on free access to uncultivated lands, and also to cultivated land after the main crop harvest is over. This has serious implications for the protection of perennial quality biomass. Moreover, continuous grazing by livestock strips the ground of cover plants as well, exposing bare soil. The continuous rise in the

human population and activities such as unorganized livestock rearing are the main factors behind land quality degradation in the project villages.

2. Improved dryland agriculture and rehabilitation of degraded areas

Excessive anthropogenic interventions during the last few decades have significantly changed the species dynamics of arid rangelands. This project activity was carried out with the participation of all the local communities. The objective was to reduce the pressure on rangelands arising from biotic and abiotic stresses. During 2010, the deferment of grazing by 2-3 months at the protected site of Bharamsar village resulted in a higher biomass in the rangelands.

The seeds of sewan grass (*Lasiurus sindicus*) and buffel grass (*Cenchrus ciliaris*) were distributed to farmers in the villages for pasture development of their fallow lands and field boundaries. The grass seeds were sown during the onset of rains, however, due to a prolonged dry spell of 25 days just after sowing, the establishment of pasture was adversely affected. Nevertheless, the intervention could potentially reduce soil loss from wind action by 15 to 20%. Growing *Ziziphus rotundifolia* grass on fallow lands and field boundaries on farmers' fields not only helped to stabilize field bunds, it also enhanced fodder availability both in terms of quantity (20–30%) and duration (35–50%). Farmers are advised and encouraged to protect and improve the existing natural pastures/grasslands adjoining their fields through the reseeding of perennial grasses, particularly *Lasiurus sindicus* grass, which is one of the most productive and nutritive grasses of the area.

3. Khadin (Runoff farming)

To understand the physical processes behind the accumulation of significant amounts of runoff water, even after a small rainfall event, the catchment area of a Khadin (runoff farming system) was delineated using the watershed delineation module ArcsSWAT 1.7. The catchment area was ~20 times greater than the cultivated area. The steady state infiltration rate at a cultivated area of the Khadin was 0.39 mm/min, whereas it was 3.75 mm/min at the gravely catchment. This indicated that rainwater entered through the soil surface of the catchment at a faster rate, and through subsurface flow slowly moved towards the cultivated area of the Khadin, thus contributing sufficient soil moisture for crop growth.

4. Soils in Bharamsar Khadin

Six pedons, two each from the upper, middle and lower reaches along two soil transects of a runoff farming system at the Bharamsar village, was taken up for morphometric study. Horizon soil samples were collected for physio-chemical analysis (Jackson, 1979) and macro and micronutrient characterization (Tisdale *et al*., 1993; Page *et al*., 1982). The salient findings of the study are as follows:

Soil texture becomes heavier from sandy loam in the upper and middle reaches to clay/sandy clay in the lower reaches, indicating an increase in the intensity of pedogenic activity from upper to lower reaches.

The pH of the soils is generally alkaline and increases from upper to lower reaches.

The soil salinity (Ece) was lower in the soils of lower reaches (0.28 to 0.97 dS) compared to middle (2.2-5.8 dS) and upper reaches.

The soils were generally saline-sodic and sodic, with an exchangeable sodium percentage (ESP) of more than 15 and electrical conductivity of more than 4 decisiemens in 70% of the total geographical area (TGA) of the surface soils. The gypsum requirement was calculated based on exchangeable percentage (ESP) and the cation exchange capacity (CEC) of the soils. For the reclamation of 60% of the sodium in the top 15 cm of the soils, 2,100 kg of gypsum per hectare is required.

Soil organic carbon (SOC) increased from upper to lower reaches.

A high amount of exchangeable sodium was observed throughout the depth of the soils of pedons studied from all reaches.

The zinc (Zn) and iron (Fe) deficiency was consistent with vertical distribution in soil pedons. Available potassium (K) is present in moderate amounts (117-280 kg ha^{-1}) in 80% of the soils in the area. The use of zinc chelates and the application of Fe as a foliar spray is recommended to ameliorate Zn and Fe deficiencies.

The thematic maps depicting the weighted average distribution of DTPA (diethylene-triamine-pentaacetic acid) extractable zinc, iron copper (Cu), manganese (Mn), and available potassium (K) and phosphorous (P) were generated using Arc GIS 9.3 platform (Fig. 2).

Figure 2.
Soil characteristics of Bharamsar Khadin.
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With the aim of increasing the production from runoff (Khadin) farming systems, low water, requiring rabi[1] crops (wheat, mustard and cumin) were taken in rabi 2010. Data on the use of the improved variety (Raj-3077) of wheat revealed a better performance compared to the conventional variety. The grain yield in Raj-3077, with 100% recommended dose of fertilizer, increased the yield by 27.71% compared to the local variety, as often practiced by the farmers. During kharif[2] 2011, nine cluster bean demonstrations were conducted on farmers' fields in Barhamsar village (Jaisalmer). Seeds of three varieties of cluster bean (RGC -936, HG-365 and RGC -1002), along with 20 kg N + 40kg P_2O^5/ha and the application of two foliar sprays of Thiourea (0.05%) and zinc sulphate (0.5%) at vegetative and reproductive stages, were taken up. The variety RGC-936 performed well compared to RGC-1002 and HG-365. Pearl millet, mung bean, moth bean and cluster bean were grown on farmers' fields with improved varieties, together with integrated nutrient management, covering an area of 22 ha (46 farmers) in kharif 2011 in Bujhawar and Rohila Kallan villages in Jodhpur district.

1 Refers to the planting, cultivation and harvesting of any domesticated plant sown during post-monsoon season.
2 Refers to the planting, cultivation and harvesting of any domesticated plant sown in the rainy (monsoon) season.

In rabi 2011, 21 field trials on improved varieties of wheat, mustard, cumin and plantago were conducted in the project villages in Jodhpur and Jaisalmer district. The introduction of improved varieties of wheat (var-Raj 4037), mustard (var-Pusa Jai Kisan), and cumin (var-GC 4), together with the application of the recommended dose of fertilizers (RDF) at Bhujawar, increased the net return by 17.26%, 29.4% and 18.18%, respectively compared to conventional practices. At Jaisalmer, the adoption of improved varieties of cumin (var-GC 4), psyllium (var-GL 2), mustard (var-Bio-902) and wheat (var-PBW-502), together with the RDF increased the grain yield by 37.1%, 46.6%, 22.9% and 34.7%, respectively compared to conventional practices.

During kharif 2012, 78 field trials covering 39 ha area were conducted on improved varieties of pearl millet (var.HHB-67), cluster bean (var.RGC-936 and RGM-112), green gram (var.GM-4, RMG-268 and SML 668), moth bean (var.CAZRI moth 3 and RMO 435) and sesame (var.GT-7, RT-127). Due to the adoption of improved varieties, the increase in yield ranged from 46.6% to 82.0% in the different dryland crops, with the maximum in green gram and the minimum in sesame.

Horticultural plants like sebesten (*Cordia dichotoma*) and jujube (*Ziziphus mauritiana* cv-Gola) were also planted in Khadin in Bharamsar village to enhance the economic return from the system. In Bhujawar, also horticultural and multi-purpose tree species (MPTS) such as jujube (*Z. mauritana*), pomegranate (*Punica granatum*), drumstick tree (*Moringa oleifera*), pongam (*Pongamia pinnata*), margosa/neem tree (*Azadirachta indica*), lebbeck tree (*Albizia lebbeck*) were also planted in 19 farmers' fields.

Furthermore, the study of Khadin areas revealed that the natural water courses are vital for the conservation of multipurpose tress/shrubs, herbs and fodder grasses. For example, *Tamarix ericoides* is naturally occurring along water channels and also on field boundaries, acting as windbreaks, and therefore requires attention if it is to be used for *in situ* conservation. Rich genetic diversity exists in *Salvadora oleoides*, particularly in Khadin areas with their varied coloured fruits (yellow, dark red, light red) (Fig. 3), requiring the *in situ* conservation of diverse germplasm on farmers' fields. The conservation and promotion of desert species like *Euphorbia caducifolia* and *Salvadora oleoides* is important for their economic value but also because they support climbing plant species like *Coccinia grandis*, *Cocculus pendulus*, *Commicarpus verticillatus*, *Rhynchosia minima* and so on, thereby conserving biodiversity. The unripe fruits of *Coccinia grandis* are collected by villagers for their own consumption and for sale in the market.

Figure 3.
Diversity in fruits of *Salvadora oleoides*. Different colours and sizes of fruits © J.P. Singh

5. Improved weeding tools to reduce drudgery

Weeding using traditional kassi (small spade) was improved to reduce pull strength and thereby minimize drudgery. Fifteen improved weeders were distributed among the farmers in order to evaluate field performance through demonstration in both Bhujawar and Rohilla Kalan during kharif season. The highest field capacity was found for the single slot weeder with a capacity of 193.4 m^2/hr and a weeding index of 94.5% compared to a field capacity of 160.5 m^2/hr and a weeding index of 91.8% in the case of the traditional kassi. Single slot kassi was also found to be suitable for women, further reducing the cost of weeding by 21.5% compared with local weeding tools (Rs. 4,800 per ha or ~ US$87).

6. Rainfall-runoff and wind erosion studies

Rainfall-runoff studies were conducted at two selected sites: one each at Bhujawar and Rohilla Kalan. The average slope of the field is 4% to 5% in a north to south direction. A detailed topographic survey of the field was conducted, and one earthen contour bund of 78 m in length and 0.4 m in height (cross section area 0.36 m^2) was constructed across the slope in the middle of field, dividing it into two parts of approximately 0.59 ha. The lower part of the field was further protected by the construction of a peripheral bund of 115 m in length along the stream. The peripheral bund was further reinforced with sand filled bags at the lowest point. The bunds helped to retain runoff to the tune of 600 m^3 –700 m^3 in each compartment with the deposition of silt at the base of the bunds. This deposition helped to reduce the effective slope. The establishment of local grasses further strengthened the bunds. The additional moisture in the compartments helped to increase crop yield by 20 to 30% over previous years, with a total yield of sesamum, green gram and pearl millet at 100, 200 and 200 kg, respectively under mixed cropping. In 2012, total seasonal rainfall of 453.3 mm was recorded with fair distribution over more than 20 rainy days. Twelve rainfall events of more than 15 mm contributed significantly towards the generation of runoff. Post and pre-monsoon observation of wells located in the nearby area

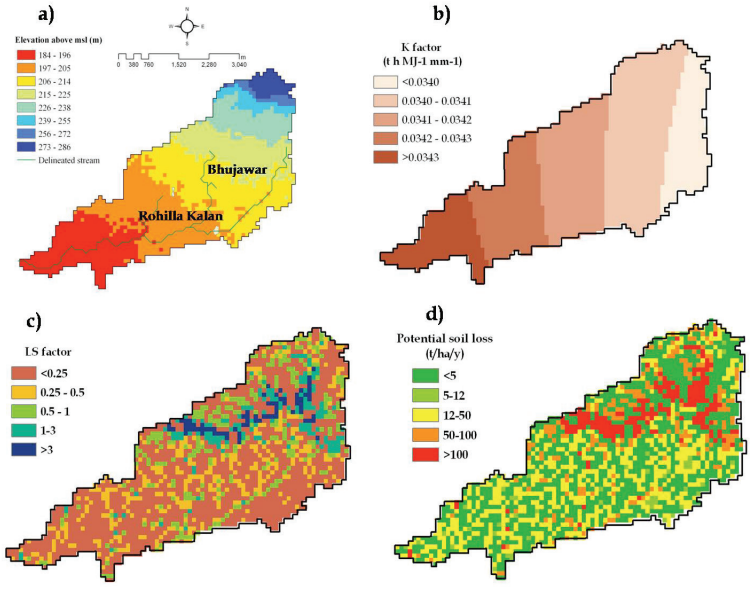

Figure 4.
Potential rate of soil loss in watershed covering Bhujawar and Rohilla Kalan village, Jodhpur: a) digital elevation model of the watershed; b) soil erodibility factor (K factor) (t h MJ^{-1} mm^{-1}); c) Slope length and steepness factor (LS factor); d) Potential rate of soil loss (t ha^{-1} y^{-1}).

indicated a rising trend of groundwater by 0.15 to 0.20 m.

Soil loss through water erosion processes in the watershed covering Bhujawar village was estimated using the universal soil loss equation (USLE) in GIS environment: A = R.K.L.S.C.P. Rainfall erodibility factor (R factor) of the watershed was 2877 MJ mm ha^{-1} h^{-1} y^{-1}, as calculated from the 50-year daily rainfall data (1960–2010) of Jodhpur station. Soil erodibility (K factor) and LS factor of the watershed is depicted in Figure 4. Cover management factor (C factor) was approximated from the thematic data on the fraction of vegetation cover of the area. Support practice factor (P factor) was approximated as 1, with the assumption that soil water conservation measures were not practiced in the watershed. Potential rate of soil loss was found to be < 12 t ha^{-1} y^{-1} in most parts of the watershed, which is considered as the tolerance limit of soil loss through the water erosion process (Fig. 4). However, soil loss rate >100t ha^{-1} y^{-1} was also observed at the hilly undulating terrain of the watershed, where large gullies were frequently observed in the field.

It has been observed that both rainfall amount and intensity are highly variable in space and time, more specifically in dryland contexts. Accurate and location specific rainfall data may help farmers make decisions based on crop-weather advisory services. Moreover, improving the utilization of scarce rainwater in drylands using modeling requires location specific data on rainfall events. To bridge this gap, a simple rainfall collector was designed and made from locally available materials (Fig. 5). The rainfall collector was then demonstrated in Bhujawar and Rohilla Kalan villages in a participatory manner and was supplied to farmers in each village. Rainfall events during August 2012 onwards were recorded by farmers and are shown in Figure 5. A large variation in recorded rainfall events was observed between Bhujawar and Rohilla Kalan village, which are only 5–6 km apart.

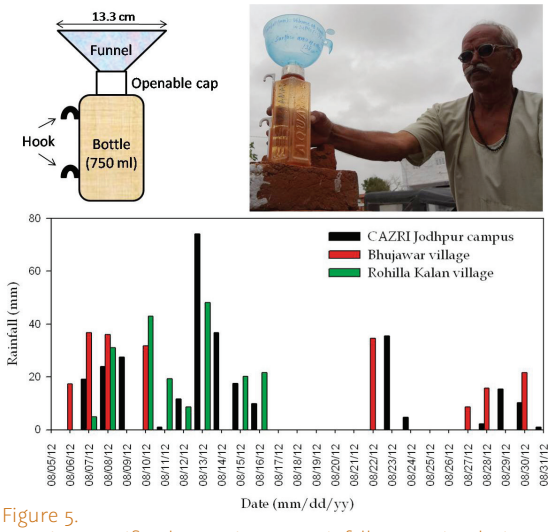

Figure 5.
Location specific observations on rainfall events in Bhujawar and Rohilla Kalan using an easy-to-make rainfall collector. © P. Santra

7. Future land use changes under climate change scenarios

7.1 Upgradation and management of rangelands

In arid regions, grasses constitute the most important forage resources for grazing animals. However, due to increases in the livestock population, forage production of rangelands is poor (~0.5 t/ha dry forage yield). The perennial grass component in the area has decreased significantly and is being replaced by annual grasses and weeds of low palatability. Furthermore, the goat population has increased considerably between 2003 and 2007, almost doubling in Jaisalmer district. The introduction of a browse component, particularly rangeland browse shrubs, is very important to small ruminants especially goats, increasing production in rangelands. Browse shrubs such as *Cordia gharaf*, *Grewia tenax*, *Heliotropium*

rariflorum, *Indigofera spp*, *Ziziphus nummularia* are promising species in this area. More emphasis is therefore required to introduce and popularize indigenous rangeland shrubs and legumes, which constitute a vital component in terms of livelihood security and the environmental sustainability of hot arid rangelands.

7.2 Developing scenarios on the maintenance and use of sacred lands in Thar Desert

Sacred lands or sacred grooves – locally known as Orans – are patches of woodlands preserved in the name of local deities and/or saints. These Orans depict the testimony of traditional conservation measures of woody perennials, and are the repositories of rich biodiversity. The total area covered by Orans in Jaisalmer district is about 76,860 ha and are composed of habitat specific species that have adapted to the harsh climatic conditions. The preliminary study of some of these Orans in Jaisalmer district reveal that they still preserve the biodiversity of trees and shrubs, particularly species like *Ziziphus nummularia*, *Acacia senegal*, *Salvadora oleoides, Capparis decidua*, *Prosopis cineraria*, and others. However, ground vegetation, particularly perennial pasture grasses, decreased to a great extent due to the increase in the livestock population and dwindling grazing lands, with Sewan (*Lasiurus sindicus*) the most affected grass. Orans currently face various threats from complex changes in socioeconomic and cultural scenarios, which had previously been a factor of stability. However, increasing grazing/browsing pressure is one of the decisive factors related to the degradation of sacred groves. If the Orans could somehow restore their potential production level, the gap between the forage supply and demand could be levelled up to some extent with added environmental benefits.

For the management and sustainable utilization of Orans, the suggested rehabilitation measures include:

- developing a database;
- ensuring community participation through awareness campaigns;
- soil and water conservation measures;
- improvement in understory vegetation cover;
- reintroduction of locally extinct and rare plant species;
- rehabilitation of water storage structures; and
- grazing/browsing policy and provision of incentives.

It is anticipated that attention towards the rehabilitation of such precious resources for scientific consideration in this region will lead to the conservation of these biodiversity heritage sites, as well as promote livestock rearing and livelihood enhancement for primary stakeholders.

8. Farming system models under changing scenarios

Even though knowledge of successful farming models is available, replicating them in farmers' fields requires certain modifications based on their needs. Hence, a survey was conducted to ascertain the farmers' requirements of species for the agroforestry (AF) model in the target village of Bujawar. Accordingly, the following crops, trees and grasses were used to develop sustainable agri-silvi-horti-pasture production systems for the farmers of these marginal drylands: jujube (*Ziziphus mauritiana*), Indian gooseberry (*Emblica officinalis*) and sebestin (*Cordia dichotoma*) for fruit crops; tree of heaven (*Ailanthus excelsa*), *Hardwickia binata* for fodder trees;

gum-Arabic (*Acacia senegal*) and pongam (*Pongamia pinnata*) for livelihood support plants; sissoo (*Dalbergia sissoo*) and desert teak or rohida (*Tecomella undulata*) for timber trees; and buffel grass (*Cenchrus ciliaris*) for pasture grass and annual monsoonal/ winter. Efforts were also initiated on three farm sites in Rohilla Kalan village to demonstrate the proper utilization of livestock excreta and farm waste through composting.

9. Modeling of wind and water erosion hazards and simulation of changing climate scenarios

The total amount of wind eroded soil loss during three months in the summer season (May–July) was 827 kg ha^{-1} at the overgrazed site, whereas it was only 240 kg ha^{-1} at the controlled grazing site. This soil loss data from rangelands of the Indian Thar Desert clearly show that controlled grazing may greatly reduce the amount of wind eroded soil loss, and consequently its negative impact on the environment. The protection of rangeland sites through fencing is therefore vital in order to sustain livelihoods in the region and to mitigate future environmental hazards from severe dust storm events.

Field measurements of wind erosion events revealed an average content of C and N in eroded soils measured as 4 g C kg^{-1} and 0.77 g N kg^{-1}, respectively. The rapid rate of land conversion in the Indian Thar Desert in recent times, mostly from native rangelands to arable lands has aggravated the problem of soil and nutrient loss through wind erosion, with an observed net loss rate of 0.23 t C ha^{-1} yr^{-1} from a farm in a project village. In continuation of the work on wind erosion research at CAZRI-Jodhpur, efforts have been initiated to model the wind eroded soil loss under the SUMAMAD project. A significant correlation ($r = 0.6$ to 0.8) was found between observed and predicted soil loss through use of a revised empirical wind erosion equation (RWEQ).

Soil erodibility and surface cover factor, as well as wind eroded mass flux at two landuse contexts in Bhujawar village in Jodhpur was determined: a) allow land (FL) and b) cultivated land (CL). Fallow land was kept as such for the last three years, and the ground surface is mainly covered with wild species such as *Crotalaria burhia*, *Ochthochloa compressa*, and *Aristida* spp. Cultivated land is mainly used for rainfed cultivation of pearl millet, sesame and green gram. The soil erodibility factor was calculated as per the revised wind erosion equation (RWEQ) and was found as 0.61 in FL and 0.59 in CL. The surface cover factor as per RWEQ was found as 0.014 in FL and almost 1 in CL, which indicated that plant cover significantly protects the surface soil from erosion. Wind eroded mass flux at 0.25 m height from surface in CL was 0.14 kg m^{-2} day^{-1} during May–June 2012.

10. Groundwater depletion in hot arid region of India vis-à-vis policy issues

Drastic changes in land use patterns in the Indian Thar Desert have been observed during the last few decades. For example, the area under rainfed cultivation in Jaisalmer district has increased by 332% during the last 30 years, while the net irrigated area has increased from a meagre value of only 110 ha during 1980–1981 to 156,897 ha during 2009–2010.

All these expansions in cultivated areas has led to the exploitation of groundwater for irrigation purposes. The spatial pattern of groundwater depletion in Jaisalmer district during the last 15 years was subsequently studied. Data on the groundwater table of 117 wells in Jaisalmer district, both during the pre- and post-monsoon season of 1995, 2004, 2008 and 2009, was used to analyse groundwater depletion patterns (Fig.6). It has been found that recharge through rainwater during the monsoon season is negligible in most of the wells. However, continuous withdrawal of groundwater for irrigation and other livelihood activities led to the fast rate of depletion of groundwater resources. The average depth of the groundwater table from the surface reduced from 42.64 m in 1995 to 45.85 m in 2009. The annual rate of groundwater depletion was 0.20 m per year. There is therefore an immediate need for appropriate groundwater management strategies in light of the above observations.

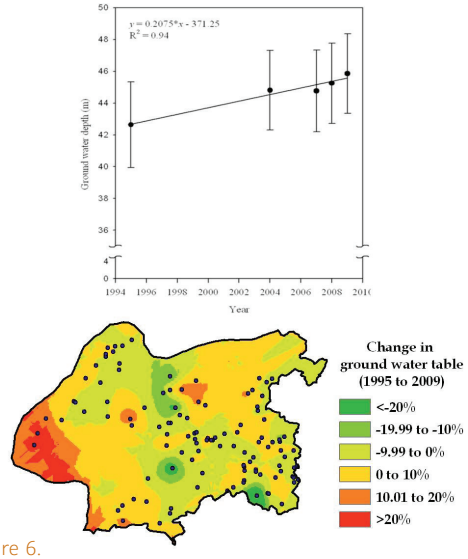

Figure 6.
Groundwater depletion pattern in Jaisalmer district and spatial trend of change in the groundwater table during 1995–2009. © M. M. Roy, T. K. Bhati and P. Santra

11. Ensuring sustainable livelihood through alternative income-generating activities and results

11.1 Use of CAZRI gum inducer in Acacia senegal and other gum-producing plants

During 2011 and 2012 (March–May), a gum induction process was attempted by injecting the CAZRI gum inducer into *Acacia senegal* (gum Arabic) trees (Fig.7 and Fig. 8), with 40 farmers from Bhujawar benefitting from this activity. Gum yield varied with the field condition (100g to 320g). Trees on the Nala (watercourse) side yielded more gum than the trees on the field boundaries. It is estimated that Rs. 80,000 (~ US$1,460) has been earned by the farmers as a result of this activity. Since a large number of *A. senegal* trees are present in Bhujawar village, the gum induction technique was also shown as hands-

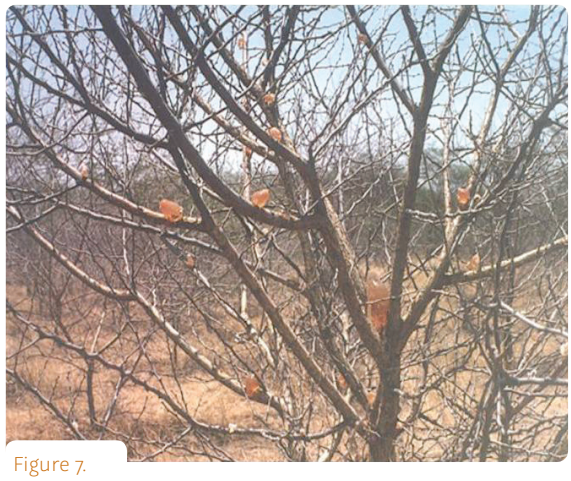

Figure 7.
CAZRI's gum inducing technology, increased gum production and sustainable utilization of *A. Senegal*. © J.C. Tewari

on training to the farmers. There are about 4,000 fully grown *A. senegal* trees and some other gum yielding Acacia species in Bujhawar, representing a great potential for the development of an organized gum production hub, which would secure the livelihoods of the rural community in this region.

11.2 Plantation of medicinal plants

With a view to enhancing livelihood security and to popularize the cultivation of endangered and high priced medicinal plants, Indian bdellium (*Commiphora wightii*) was planted on farmers' fields during August 2011 at two sites in Bharahamsar village, which recorded 70% plant survival. In sandy areas, rangelands dominated by *Panicum turgidum* was identified for the introduction of threatened arid medicinal plant species like *Caralluma edulis*. Its green succulent stems are used as a vegetable in rural areas and it has high medicinal value. *C. edulis* planting material was collected for multiplication and planting in the fields. Furthermore, farmers were advised to collect some medicinal plants that grow wild in the area such as: *Barleria acanthoides*, *Boerhavia diffusa*, *Convolvulus arvensis*, *Cressa cretica*, *Citrullus colocynthis*, *Mollugo cerivіana*, *Tribulus terrestris*, and others for sale in the market.

Figure 8.
Smiling faces of farmers with their gum Arabic product
© J.C. Tewari

11.3 Field nurseries

Two field nurseries were developed in Bhujawar to raise seedlings of multi-purpose tree species (MPTS) such as *Prosopis cineraria*, *Tecomella undulata*, *Pongamia pinnata*, *Ailanthus excelsa*, *Azadirachta indica*, among others (Fig. 9). About 5,000 seedlings were raised in these nurseries and distributed to farmers. These planting materials therefore helped to improve the biodiversity of villages and also to increase the income of the owners of the nurseries to the tune of Rs. 12,500 per farmer (~ US$228). This activity has high potential as an extra income for the farmers concerned.

Figure 9.
Farmers' participatory nurseries in Bujhawar village
© P. Rathakrishnan

11.4 In situ budding of jujube *(Ziziphus spp.)* and khejri *(Prosopis cineraria)*

Budding of *Ziziphus mauritiana* on to the root stocks of *Z. rotundifolia* (wild cultivar) *in situ* is a perfected technology being routinely used for raising improved jujube plantations. Hence, attempts were made to demonstrate this technique to convert the *Z. rotundifolia* plants into improved cultivars, and about 50 plants located on eight farmers' fields in Rhohila Kalan village were taken. During the activity of *in situ* budding, the interested youths of the village were also exposed to the technique. Work also began on *in situ* budding of *Prosopis cineraria*, a life sustaining tree of the Thar Desert, to make use of the properties of this plant as a vegetable tree.

11.5 Promotion of renewable energy devices

A solar cooker was installed in Bhujawar and in Rohilla Kalan. Average fuel wood savings from these cookers was 1.05 tonnes per annum per farm/family or 3611 MJ of energy with a time saving of about 20–25%. Moreover, huge amounts of firewood, animal dung cake and agricultural waste are needed to fuel traditional wood stoves to boil animal feed. Taking this into account, a novel solar cooker using locally available materials (e.g. clay, pearl millet husk and animal dung) has been designed, developed and tested, which can boil 10 kg of animal feed per day. Performance is very good during the summer but poor on days of extreme cold. The addition of a reflector in the cooker resulted in a 15°C rise in temperature and improved its efficiency in winter. Crushed barley (jau ghat), cluster bean seed husk (guar korma), and gram seed splits (gram churi) with water were kept at 9.00 am and successfully boiled by 4.00 pm. The solar cooker is easy to make at the village level with the help of a mason and carpenter.

A wax melter of overall size (0.6 x 0.9 x 0.2 m), which had previously been designed and developed in the institute was produced for installation in the villages with a capacity of 6-10 kg/ day. In addition, a couple of candle moulds were also distributed to some farm families with a capacity of making 12 candles at a time.

12. Demonstration on compost preparation from unutilized farm waste and brush wood material

Demonstrations on how to prepare quality compost on farmers' fields from their own farm waste and local brush wood material was carried out. Four compost pits of 15x5x3 m with a capacity of 0.5 tonnes of compost from each pit were constructed on three farmers' fields at Bhujawar and one at Rohilla Kalan. Compost pits were turned at an interval of one month followed by moistening of the material with water. After a third turning, rock phosphate powder was mixed into the compost pits. The compost was ready for field application after five months. The prepared compost contained about 15.5–19.7% organic carbon, 0.71–0.96% total nitrogen, 0.28–0.74% total phosphorus and 0.25–0.45 % potassium, respectively. The C:N ration of the compost was 20–22.

13. Fodder enrichment through urea treatment

Ten field demonstrations on the enrichment of poor-quality dry fodder through urea treatment were made to increase the awareness of farmers regarding nutritive animal feed. A total of 104 farmers from

both Bhujawar and Rohilla Kalan participated in the field demonstrations on enriching fodder quality through urea treatment. To improve the acceptability and palatability of urea treated fodder, a minor quantity of jaggary is added to the treated fodder before feeding the animals.

14. Use of multi-nutrient block and mineral mixture as animal feed

Farm trials for feeding bovine with a supplement of multi nutrient block (MNB) was conducted on 30 farmers' fields. Eight blocks were provided to each animal for a period of 2–3 months. The effect of block licking was very clear on daily milk yield (DMY) and on the overall health of the animals. The response of farmers towards MNB was very positive, and as a result of this intervention improved the daily milk yield of their cattle and buffalo by 10–20%.

Trials on the use of multi-nutrient mixture (MNM) in small ruminants were conducted on 28 farmers' fields in two villages. This mixture was supplemented to the lactating goats at 100g/day/goat for the period of three months. The MN mixture was formulated at CAZRI and was composed of molasses, urea, common salt, vitamin mineral mixture, dolomite, wheat bran, guar meal and crop straw. This supplement significantly increased the milk yield of goats from 1.20 to 1.48 litres (23.3%).

15. Use of vitamin mineral mixture as animal feed

Vitamin mineral mixture (Nutrimilk) was provided to 12 farmers for feeding cattle, sheep and goats (4 farmers each) in Bharmsar. The nutrimilk was mixed with feed for lactating cows at 50g (25g in the morning and evening) and 5g per day for goat and sheep. The results of the preliminary six months indicated an increase in milk yield in cattle and an improvement in the health of the animals.

16. National workshop

A national workshop on 'Rehabilitation of degraded rangelands for sustainable livelihood of the Thar desert' was organized in Jaisalmer on 5 September, 2012. A total of 58 delegates representing policy-makers, researchers, academics, state department officials, farmers, NGOs, and social activists participated in the workshop. Proceedings of the workshop were also prepared. The main themes discussed by the participants were:

- Rehabilitation of degraded rangeland: issues and opportunities.
- Range based livelihood support systems: potential and possibilities.
- Developmental decision support systems: policies and programme.

17. Capacity-building

17.1 Animal health camps

Four off-campus animal health camps were organized in Bhujawar and Rohilla Kalan during 2011 and 2012. In these camps animals under different categories, including cattle (163), buffalo (84), goat (1364), sheep (587), and camel (8), were treated for various diseases. All animals were de-wormed with broad spectrum anti-helminitic. More than half of the cattle and buffalo were found to be deficient in

body mineral content. Some cattle and buffalo were shown to have reproductive disorders (e.g. repeat breeding, anoestrus or pyometra). Some goats were found with orexia and debility conditions. All animals were examined and treated with appropriate medicines.

17.2 Field days for improved crop production technology

Field days on improving technology of rabi crops was organized in Bharamsar on 22 February, 2012 and in Bhujawar on 2 March, 2012.

17.3 Training programmes

A one-day farmer training programme on 'Pasture Development and Management' was organized on 12 September 2011 for the farmers of Bharamsar village. The farm visit and lectures were conducted to acquaint the farmers with appropriate pasture development and seed collection techniques, particularly with regards to *Lasiurus sindicus*. Discussions were also held with the farmers to enhance rangelands productivity through the use of water and moisture conservation techniques, improved forage diversity, nutrient management, and the management of weeds by introducing mix herd grazing. A one-day farmer training programme on 'nursery management' was organized on 16 March 2012 for the farmers of Bharamsar village to acquaint them with the efficient development of MPTS nurseries. Two training programmes on rainy season crops were also organized during July 2012 in Bhujawar and Rohilla Kalan villages, which benefited 190 farmers.

18. Recommendation for sustainable dryland management

Wind erosion is a severe land degradation problem in the region, and it has been observed that the protection of land surface through perennial grass cover can greatly reduce the extent of soil loss. It has also been observed through modeling that an increase in wind speed in the future may lead to a four-fold increase in soil loss, suggesting that a protective vegetative cover of grasslands/rangelands may play a major role in reducing the severity of wind erosion.

A number of remedial steps are required to improve the degraded rangelands and sacred groves (Orans) from a botanical and habitat perspective. These steps include protection over a specific period through a variety of fencing/hedges, the removal of bushes especially undesirable ones, and the reseeding/planting of suitable indigenous grasses, shrubs and trees as required of the habitat and grazing management strategies.

In arid regions, the planting of trees along with crop/grasses has great potential to enhance productivity. Accordingly, the following crops, plants, trees and grasses can be considered for sustainable agri-silvi-horti-pasture production systems of marginal drylands: *Ziziphus mauritiana*, *Emblica officinalis* and *Cordia dichotoma* for fruit crops; *Ailanthus excelsa*, *Hardwickia binata* for fodder trees; *Acacia senegal* and *Pongamia pinnata* for livelihood support plants; *Dalbergia sissoo* and *Tecomella undulata* for timber trees; and *Cenchrus ciliaris* and *Lasiurus sindicus* for pasture grasses and annual monsoonal/winter crops. Efforts need to be made to popularize these integrated farming system models, which are suited

to particular micro-farming contexts for sustainable production and economic stability.

The construction of peripheral earthen bunds using sand filled bags across the field slope was found to be an effective method of preventing the loss of fertile topsoil through runoff water, while conserving soil moisture during the monsoon season. As a result, crop growth and yield were found to be satisfactory when compared with fields without bunds. There is therefore a need to popularize this technology.

Groundwater in the <200 mm rainfall zone showed a rapid decline despite some recharge through rainwater, which is nonetheless negligible and thus requires efficient groundwater management. The various management options available for solving the problem of groundwater quality and quantity can be broadly grouped under two major categories. The first category relates to supply side management, which involves scientific development and an augmentation of groundwater resources. The second category relates to groundwater recharge through structures like check dams, sub-surface dykes, gabion structures, percolation tanks, and injection wells, as well as the adoption of efficient irrigation and so on.

Improved varieties of pearl millet, green gram, moth bean, cluster bean, along with integrated nutrient management practices, resulted in better yields than under traditional farmers' practice in Jodhpur (200–400 mm rainfall zone) and in Jaisalmer (<200 mm rainfall zone). Recommended nutrient management can play a pivotal role in significantly increasing productivity and economic returns from annual crops in the area. Efforts are therefore required to implement state and national level extension systems to popularize the use of improved varieties with the recommended dose of fertilizers.

It was consistently found over two years (2011–2012) that a single-slot kassi with a slot opening of 90 mm was better in terms of weeding index than the local kassi used by farmers in the region for weeding in the field. The single slot kassi should therefore be promoted among farmers to reduce drudgery and save time.

The efficient utilization of farm waste and other unproductive plant biomass generated from community lands can be used for making compost whose preparation techniques should be promoted in the Thar Desert. Making compost and its effective use in crops will not only boost productivity, but will also help stabilize the soil and conserve moisture.

CAZRI gum inducer was found to be an effective way to enhance gum yield from *Acacia senegal* and thus increase farmer's income. Gum inducing technology should therefore be promoted among farmers, especially as many gum inducing tree species are found in the rural landscape of the Thar Desert. Conversion of wild jujube (*Ziziphus rotundifolia*) to improved jujube (*Z. mauritiana*) through *in situ* budding was found to be successful in farmers' fields and thus has significant potential to enhance the farmers' income.

The popularization of farmer nurseries can be another way to enhance livelihood opportunities and increase plant biodiversity on marginal drylands in the Thar Desert. This strategy therefore requires the attention of planners for large scale schemes in this direction.

Supplementing bovine feed with vitamins and minerals, nutrient mixture and MNB was found to be an effective way to enhance milk production, suggesting that such types of animal feed should be promoted among farmers through policy measures. The enrichment of poor quality dry fodder through urea treatment was also found to be a cost effective method of increasing the milk yield of cattle and hence needs to be popularized among farmers.

The animal feed solar cooker was found to be an effective way to boil animal feed using solar energy, thus saving on fuel costs and minimizing the carbon load in the atmosphere. Consequently, this renewable energy based device has become popular among farmers and hence needs to be promoted, bearing in mind future energy crisis scenarios.

19. Problems and challenges

The distribution of monsoonal rains was uneven during 2011 and 2012 and had an adverse impact on the productivity of rainfed crops, particularly on rangelands and pasture development activities. The low literacy rate and poor awareness among the farmers of the Thar Desert also substantially hampered project activities.

20. Research institution and team composition

Partner institution
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Dr. A.K. Patel
Principal Scientist in Livestock Management

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Sr. Scientist in Soil Physics

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Sr. Scientist in Pedology

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Er. D. Mishra
Principal Scientist in Farm Machinery

Dr. A.K. Singh
Sr. Scientist in Farm Machinery

Other experts at CAZRI Jaisalmer
Dr. Hans Raj Mahla
Sr. Scientist in Plant Breeding

21. Publications as a result of SUMAMAD

Abstract in seminar/symposium

Raja, P., Sinha, N.K., Singh, J.P. and Daleep Singh. 2011. *Morphometric characterization in a soil transect of runoff farming system (Khadin) in Bharamasdar village, Jaisalmer district, Rajasthan*. In: National Symposium on Resource Utilization through Integrated Farming System and Biodiversity Conservation in Drylands. December 20-22, 2011. pp. 39. CAZRI, RRS, Kukama, Bhuj.

Raja, P. Praveen-Kumar, N.K. Sinha, P. Santra, J.P. Singh, T.K. Bhati and M.M. Roy. 2012. *Study on micronutrients availability in the soils of Bharamsar Khadin, Jaisalmer district, Western Rajasthan*. In: Symposium on Managing Stress in Drylands under Climate Change Scenarios. AZRAI, CAZRI, Jodhpur. December 1-2, 2012. pp. 189–190.

Santra, P., Bhati, T.K., Inakhiya, N.D., Kumawat, R.N., Roy, M.M. 2012. *Groundwater depletion vis-à-vis energy and food security in hot arid region of India – a case study*. In: Proceedings of the International workshop on understanding water-energy-GHG nexus for future water and food security. Indian Society of water Management and The University of Melbourne New Delhi, India p. 32.

Singh, J.P., Roy, M.M. and Sinha, N.K. 2011.*Sustainable approaches for rangeland management and livestock production in extremely arid region of India*. p. 107. In: National Symposium on Forage Resource and Livestock for Livelihood Environment and Nutritional Security. September 10-11, 2011. RMSI, IGFRI, Jhansi.

Singh, J.P., M.M. Roy and T.K. Bhati. 2012. *Rehabilitation of Orans (sacred groves) in western Rajasthan: An Overview*. In: Symposium on Managing Stress in Drylands under Climate Change Scenarios. AZRAI, CAZRI, Jodhpur. December 1-2, 2012. pp. 226–227.

Folders for farmers

Sinha, N.K., P. Raja, Dayanand and J.P. Singh. 2011. *Sewan ghas se adhik beej utpadan taknik*. (In Hindi)

Dayanand, H.R., Mahla, N.K. Sinha, P. Raja and J.P. Singh. 2012. *Shush khetro men charaghao ka vikas avm prabandhan*. (In Hindi)

Dayanand, H.R., Mahla, N.K. Sinha, P. Raja and J.P. Singh. 2012. *Rabi faslon men unnat shasya kiryaen*. (In Hindi)

Sinha, N.K., P. Raja, Dayanand and J.P. Singh. 2012. *Guggal ki podhashala prabandhan*. (In Hindi)

22. References

Boffa, J.M. 1999. *Agroforestry parklands in sub-Saharan Africa*. Food and Agriculture Organization of the United Nations, Rome p.230.

Jackson, M.L. 1979. *Soil Chemical Analysis-Advanced Course*, 2nd Ed. Published by the author, University of Wisconsin, Madison, WI.

Narain,P. and Tewari, J.C.2001. *Agroforestry and soil conservation in arid regions of India*. In: Proc First Regional Workshop on Thematic Programme Network-2 on Agroforestry and Soil Conservation (UNCCD). ICRISAT, Hyderabad, India. pp. 3–13.

Page, A.L., Miller, R.H. and Keeney, D.R. (eds.) 1982. *Methods of Soil Analysis, Part 2*. Chemical and Microbiological Properties, 2nd Ed. Agronomy series no. 9, ASA, SSSA, Madison, Wisconsin, USA.

Tisdale, S.L., Nelson, W.L., Beaton, D.J. and Havlin, J.L. 1993. *Soil Fertility and Fertilizers*. Prentice Hall of India Ltd.p. 634.

AQUITOPIA
(An Aquifer Management-based Utopia), Gareh Bygone Plain

Compiled by Mansour Esfandiari Baiat, Mehrdad Mohammadnia and Mohammad Hossein Ravanbakhsh

Research Society for Sustainable Rehabilitation of Drylands and Fars
Research Center for Agriculture and Natural Resources

Islamic Republic of Iran

Executive summary

The Sustainable Management of Marginal Drylands (SUMAMAD) project is being carried out under the aegis of UNU-INWEH and UNESCO-MAB. The Iranian project was initiated to study the role of aquifer management on the different aspects of desertification control through floodwater harvesting. The Research Society for Sustainable Rehabilitation of Drylands (REaSSURED) – a registered scientific NGO – is responsible for planning and implementing the project in the Islamic Republic of Iran. AQUITOPIA (an aquifer management based utopia) – a proposed project in Phase I of the SUMAMAD project – is being governed by an executive committee comprised of representatives from four cooperatives and REaSSURED experts. The SUMAMAD project in I.R. Iran consists of scientific studies, policy relevant analyses, and activities for fostering sustainable livelihoods.

The main proposed activities for Phase II of the SUMAMAD project in Iran include: empowering the cooperative members to complete the AQUITOPIA project; managing the project sustainably; and benefitting from its income-generating activities. The main objectives of Phase II include: building capacity among members of the four local cooperatives working in soil and water conservation; continuing research activities initiated in Phase I; implementing the newly proposed research activities; sharing our experiences of water harvesting and soil and water conservation for the sustainable development of drylands with other countries involved in the SUMAMAD project, and encouraging the Iranian government authorities to fund the AQUITOPIA Project.

In 2009, 162 ha of the floodwater spreading system was installed with US$ 220,000 provided by SUMAMAD and the I. R. of Iran. This operation comprised of 38,117.76 m^3 of earthworks and 2,631.2 m^3 of masonry hydraulic structures. In 2010, 120 ha of floodwater spreading systems was constructed using US$ 50,000 allocated by the I. R. of Iran in Ahmadabad – the site of AQUITOPIA. Surveying for this activity was performed by Fars Research Center for Agriculture and Natural Resources.

1. Introduction

The project acquired 1,070 ha of a degraded rangeland near the Ahmad Abad village in the southwest of Gareh Bygone Plain (28°35′N; 53°53′ E), which is 1,150 m above sea level and 210 km southeast of Shiraz, Iran. This project is based on aquifer management (AM), which involves the application of floodwater spreading (FWS) for the artificial recharge of groundwater (ARG), as well as the improvement of water-use efficiency (WUE). The inhabitants of four farming communities surrounding the AQUITOPIA project were convinced to form cooperatives to construct the ARG system and thus benefit from managing the aquifer for specific purposes. The cooperatives were duly registered.

The study phase of the project began with a grant donated by UNU in 2003. SUMAMAD and the Iranian government financed the construction of 220 ha of an ARG system (618 ha). The construction of the remaining ARG system (398 ha) necessitated drilling water wells, equipping them with pumping stations, laser land levelling (451 ha), and tree planting, all of which cost about US$ 2.5 million. Another US$ 3 million would be required to establish a 'green village' for 110 households. The bulk of funds will be provided through low interest, long duration loans supplied to the cooperatives by the Iranian government. Assuming that the necessary funds are received, the construction phase of the project will be completed by December 2013.

2. SUMAMAD project objectives and implementation

2.1 Specific objectives

Specific objectives of the project include:

- The supply of irrigation and safe drinking water.
- The construction of a green village, providing livelihoods for 110 households.
- The implementation of integrated, sustainable natural resources management and research projects (water productivity in agriculture, rangeland management, horticulture, animal husbandry, bee-keeping and conservation of natural resources).
- The provision of good quality, coarse-grained alluvial aquifers, which are worth more than oil for desert dwellers.
- Demonstrable proof that, if used wisely, a sub-marginal resource (the degraded rangelands) and a marginal resource (floodwater) could provide a decent livelihood, providing there is motivation driving the project.

2.2 Major activities

Major activities of the Iranian case include:

- The completion and maintenance of 220 ha of FWS system that was constructed during Phase I of the SUMAMAD project.
- The construction of a new FWS system over 398 ha for the artificial recharge of groundwater.
- The preparation of 451 ha of land for irrigation.
- The registration of two additional cooperatives by two of the villages benefiting from the ARG system.
- The implementation of action research projects for the wise management of natural resources.
- Capacity-building of the cooperative members to enable them to act as honorary extension agents.
- The introduction of income-generating alternatives to the cooperatives.
- The introduction of soil and water conservation technologies to the cooperatives.
- Networking with environment related NGOs.
- Campaigning for the inclusion of aquifer management in a global water harnessing policy.

3. Five-year work plan for Phase II of the SUMAMAD project

Our NGO (REaSSURED) is registered by the Iranian government. We believe that the sustainable management of natural resources in drylands can be achieved through participatory approaches involving the inhabitants in the same area. AQUITOPIA will be governed by an executive committee, comprising representatives of the cooperatives and our NGO.

The main proposed activities for Phase II of the SUMAMAD project include:

- Empowerment of members of the cooperatives to complete the AQUITOPIA project, to manage it and to benefit from it.
- The introduction of income-generating alternatives.
- The introduction of soil and water conservation technologies to cooperatives.

- The continuation of research activities, which were started during Phase I of SUMAMAD.
- The implementation of new proposed research activities for Phase II of SUMAMAD.
- The sharing of experiences in the field of water harvesting, and soil and water conservation technologies through the sustainable development of drylands with other countries involved in the SUMAMAD project.
- Encouraging the Iranian government authorities to fund the AQUITOPIA project.

Final reports of SUMAMAD sub-projects

The sub-project's final report of SUMAMAD Phase II in Gareh Bygone Plain is presented below. The report focuses on the technical, environmental and socioeconomic assessments of activities conducted at the study site.

4. Efficiency of flood water spreading on net recharge of the aquifer, Gareh Bygone

4.1 Introduction

Despite the obvious positive impacts of floodwater spreading (FWS) on groundwater recharge and the rehabilitation of a sandy desert environment in the Gareh Bygone Plain (GBP), there is a permanent recession trend in the groundwater level in its aquifer. In order to quantify the role of FWS on net recharge, the water balance components, including the intake and uptake parts, need to be known. Pumping water for agriculture, and uptake of water by trees planted in the project area are the main uptake sources of reserved groundwater. However, the exact amount is unknown. As a rule of thumb, hydrologic balance studies cannot achieve a close estimate of water withdrawal; instead, a methodical soil hydrologic balance study must be undertaken.

The objective of this research is to determine the portion of diverted floodwater that contributes to the net recharge in a basin in the GBP. This is achieved by collecting scientifically approved data showing the real impact of FWS on net recharge. This would help to inform GBP decision-makers of ways to manage water withdrawal and so guarantee the sustainable management of groundwater and prevent the recession trend. Quantified results will also clarify the importance of FWS for dissemination as an environmentally friendly, small-scale water-harvesting project.

The objectives are more suited to the first outline of the SUMAMAD project (fostering scientific drylands research), described as the improvement of dryland agriculture (crop and livestock production) through the sustainable use of natural resources, focusing on sustainable water conservation and harvesting practices.

In order to reach the target, the physical behaviour of the vadose zone must first be studied. Secondly, the downward and upward movement of water through the profile between flooding events must be controlled. The results must then be applied for soil-water flux simulation, and finally the net recharge calculation. The study area is located in a floodwater spreading system called Bisheh Zard$_1$ (BZ$_1$), covering 27.25 ha, part of the Kowsar research station in Gareh Bygone Plain (Fig. 1).

The plan of action (PAC) is summarized below:

Soil-water studies

- Fieldwork in the Gareh Bygone Plain (study site in Iran).

- Implementation of the main setup of one of the experimental wells.
- Characterization of the vadose zone materials based on the profile layers, including layer description and determination of saturated hydraulic conductivity, bulk density, and texture. Calibration of the Time Domain Reflectometers (TDR) sensors.
- Insulation of one of the experimental wells.
- Soil moisture monitoring during flooding intervals.
- Simulation of water movement through the vadose zone.
- Surface topography of the study basin.

Piezometric level data collection and analysis

- Recording the flood water volume diverted to the FWS system.

Plant-water studies

- Sap flow meter (SFM) measurements to determine transpiration rate of the planted trees.
- Application of remote sensing for seasonal actual evapotranspiration mapping.

Determination of the net recharge in flooding events based on a soil-water balance approach

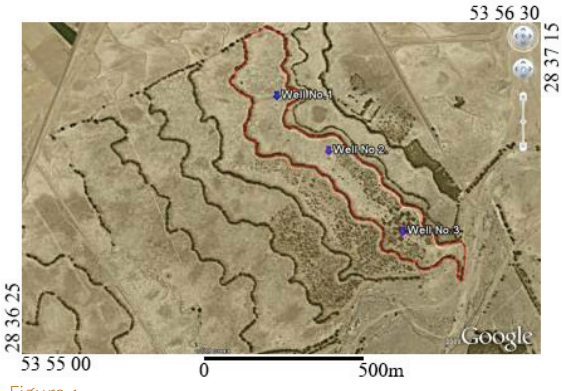

Figure 1.
The Google Earth image of the study area showing the location of the second strip of BZ_1 (study site) and the experimental wells. ©Google Earth

4.2 Activities

4.2.1 Soil-water studies

The main concept that is followed in this part is to define the soil-water balance parameters during the time intervals of flooding events. The aquifer was first discretized by observing and sampling the profile of the three wells at a depth of 30 metres inside the study area. In addition, the main hydraulic properties of pre-defined layers were measured. There have been 11 unique layers that were repeated in 25 horizons throughout the profiles. Field measurements of saturated hydraulic conductivity for all the horizons were included (Fig. 3a).

Bulk density

Laboratory analysis of the characteristic curve of soil moisture and soil texture was included. One of the wells became fully equipped for soil moisture monitoring by TDR sensors (Fig. 3b). The occurrence of a flood on 31 January 2011 triggered the start of the expected research focus. Measurements were taken at twice-a-day intervals from 31 January to 21 March 2011, and then changed to weekly intervals.

Rainfall depth and volume of water harvested by the FWS system

A standard rain gauge is being used to measure the amount of rainfall at a weather station located in the study area. The floodwater height in the main stream, and the part diverted into the FWS system, is being recorded at two hydrometric stations.

Water flow simulation

To simulate the water movement through the profile, a period of 650 days of data collection was introduced to the Hydrus 1D software latest version 4.15.0110 (PC-Progress s. r. o).

4.2.2 Plant-water studies

Sap flow measurements

In order to identify the water consumption of planted trees, a setup of sap flow sensing was established. The placement of the sap flow meter was changed to another recharge basin in the study area in July 2011 so as to collect data from a tree with certain specifications. A 25-year-old *Eucalyptus camaldulensis* Dehnh. tree, representative of a dense forest in the study area, was selected and a sap flow meter installed on its trunk at a height of 6 metres (Fig. 3c). The meter measures and records sap flow at 15-minute intervals.

4.2.3 Results obtained

Some of the preliminary results were published in a national journal (Ghahari *et al.,* 2009) and presented at the National SUMAMAD workshops. The full texts are published in the workshop proceedings (Pakparvar, 2010; Pakparvar and Hashemi, 2010).

Some of the prominent results obtained were as follows:

- During the period of TDR measurements, rainfall was mainly concentrated in late February to mid-March 2011.
- The main event lasted from 27 January to 3 February 2011.
- A total amount of 145 mm of rain was recorded.
- Flooding started on 31 January and continued to 3 February 2011. During those days 49 hours of flood, flow was recorded.
- Changes in water content of the vadose zone layers are depicted in Figure 2.
- It was observed that soil moisture content of all layers is relatively constant before the flooding event.

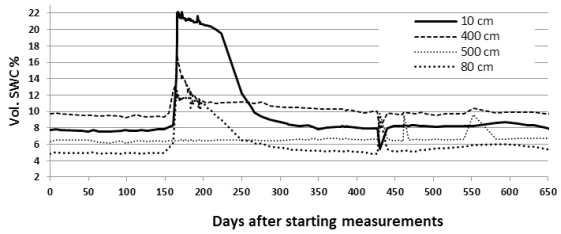

Figure 2.
Changes in water content of different layers for the period July 2010 to June 2011. © Mojtaba Pakparvar, FRCANR, 2011

There was an instant change in soil water content (SWC) after initiation of recharge. It took less than 24 hours for the wetting front to reach a depth of 400 cm. SWC remained constant in the deeper layers before and after the flooding event. Therefore, the saturated flow created the mass movement from the surface to the mentioned depth. Soil water movement will shift to an unsaturated state from 400 cm downward to an uncertain depth, depending on many parameters. However, the piston flow is expected in later recharge events.

Subtracting the depth of rainfall from the recharged water shows that 305 mm of the infiltrated water was due to the harvested floodwater. Assuming that the research site is representative of the 2,033 ha ARG system in the GBP, and that only 75 per cent of the system functioned as desired, upwards of 4.65 million m^3 was harvested in that event, which is equal to 67 per cent of flood water diverted to the FWS system. This emphasizes the adequacy of surface permeability in permitting the floodwater to enter the deeper layers, which obviously negates the hypothesis of soil surface clogging due to sedimentation in the FWS systems. This will help to implement a systemic approach for water consumption on the basis of eventual recharge in order to provide contingency groundwater reserves for future drought periods, and to prevent saltwater intrusion into the freshwater aquifers in the Gareh Bygone Plain.

4.2.4 Take-home message for decision-makers

It is of vital importance to realize that the era of cheap water is over. The most important outgoing result of this research is to turn a light to the reality of floodwater spreading impacting on the provision of groundwater in GBP. Nevertheless, from a near stable recession trend in groundwater level in recent years, the share of FWS on ARG has continued. The very unique setup of data collection has shown that more than 67 per cent of floodwater has infiltrated to the aquifer layer. In spite of some opposition from within the country against the FWS concept, the efficiency of the GBP project has been proven. About five million m^3 of water reached the groundwater in one normal event, which means that an inexpensive water harvesting project could produce and preserve freshwater free of charge in a safe place that is the natural aquifer – its original home.

Acknowledgments

The Fars Research Center for Agriculture and Natural Resources provided the logistics and accommodation facilities at the Kowsar Research Station. Mr Ali Fereidoonian, Mr Gholamali Nekooian and Mr Amir Arkia contributed extensively to the fieldwork.

5. Alternative income-generating activities in Gareh Bygone Plain

5.1 Introduction

Agriculture is the largest user of the global water supply in many parts of Iran; it is a sector where employment does not necessarily ensure an adequate quality of life or working conditions. Decent employment opportunities need to be recognized as a means to achieve poverty reduction and to improve livelihoods. In many rural areas, the income generated from common resources forms the bulk of household incomes of the rural poor, who lack the resources, information or access to services that can anticipate environmental stress.

The Participatory Rural Appraisal (PRA) used in this study, is a learning method that helps villagers recognise, analyse and evaluate limitations and opportunities, as well as to raise awareness and help make decisions during development projects.

Figure 3.
Field activities:
a) hydraulic conductivity measurement in wells;
b) the TDR data collection setup in insulated well;
c) Installing the Sap Flow Meter device for the transpiration of Eucalyptus trees.
© Mojtaba Pakparvar, FRCANR, 2011

The projects were also evaluated using economic methods such as benefit-cost ratio and Internal Rate of Return (IRR). The necessary data were collected and the calculations were made. The present project is important in assessing the employment opportunities that exist for farmers in drought prone areas in Gareh Bygone plain. The main goal of this project is to produce an economic evaluation of alternative activities that can generate income for small farmers, especially in drought conditions, so as to prevent migration, negative impacts on natural resources, and to increase employment opportunities and welfare in rural areas.

5.2 Methodology

In this study, both qualitative methods (PRA method, focus group method and in-depth interviews with key informants), and quantitative methods (household survey through questionnaire administration) were applied. Finally, villagers were asked to propose projects to overcome the limitations. Using economic methods, such as benefit-cost ratio and Internal Rate of Return (IRR), the proposed project and similar projects were evaluated using equations 1 and 2.

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} R_t \Big/ (1+r)^t}{\sum_{t=1}^{T} C_t \Big/ (1+r)^t} \qquad (1)$$

$$NPV = \sum (R_t - C_t)/(1+r)^t = 0 \qquad (2)$$

Where NPV indicates the net present value, Rt and Ct represents the revenue and cost of the project, and r is the discount rate.

5.2.1 Findings of the study

Based on the methodology used in this study, the participation of local groups within a people-oriented approach is crucial to achieving sustainable development. In fact, participatory decision-making and sharing responsibilities are the most important elements of true participation. According to this method, the villagers are the innovators and have the ability to recognise and analyse the challenges with which they are confronted.

Using these research methods, the needs and challenges of the villagers were identified during the first stage. The results indicate that the average population growth rate in the villages of the study area over the decade 1986–96 was low (0.28%), while the rate in the subsequent decade 1996–2006 even turned negative (-0.25%). Compared with the average population growth rate of rural areas in Iran, the results indicated that out-migration, from the study area towards urban environments or other districts, was taking place.

The results of the study showed that in 81 per cent of the households surveyed, only the head of the household was employed, with agriculture the main activity in the study area. However, the eight villages surveyed showed different levels of engagement in agricultural activities. Based on the results of the household questionnaires, the wealth ranking level of the households in the study area was determined as average, poor or very poor, with no household enjoying a good level of welfare. Results indicate that greater vulnerability reflected the higher levels of poverty in the study area.

During the last decade, information gathered from key informants indicated that migration to cities and other rural areas occurred in 75 per cent of villages. Unemployment and out-migration are the two main

results of groundwater recession and degradation. The results show a low participation of rural households in social networks due to low awareness and a lack of belief in collective activities, and therefore a low likelihood of coping with emergency situations.

5.2.2 Selected agricultural projects

One of the key objectives is to increase the number of productive job opportunities in order to reduce unemployment, which may be different from the objective of income distribution itself. Economic analyses of agricultural projects were undertaken to compare costs with benefits, and determine which alternative projects have an acceptable return. The costs and benefits of proposed projects are identified in Table 1. The chosen projects are those with a benefit–cost ratio more than 1.

Moreover, the results of the research indicate that there is no job diversification in the study area and that in more than 80 per cent of households only one person was employed. Most of them are poor and very poor, whose situation would worsen in a period of crisis. The households have no savings and their main financial source is Agricultural Bank credit with legal restrictions and limitations. Although all households have used credits from the Agricultural Bank in their lifetimes, limitations in credit amount and period are imposed on farmers.

TABLE 1.
ECONOMIC ANALYSIS OF THE SELECTED PROJECTS.

	Project title	Employ-ment	IRR	B/C
1	Broiler chicken farming	8	29.3	1.12
2	Apiculture	8	60	1.07
3	Mushroom production	8	58	<1
4	Breeding of medicinal plants	6	22.5	1.78
5	Artificial recharge (shifting agricultural lands to gardens)	-	-	2.36
6	Greenhouse production (tomato)	5	23	1.52
7	Greenhouse production (cucumber)	-	-	1.09
8	Breeding turkeys	-	60	1.41
9	Citrus nursery	-	60	1.06
10	Breeding of ornamental plants	11	50	4.66
11	Garden construction	-	15	3.5
12	Strawberry production (hydroponic)	-	41	1.16
13	Pickles and jam production	-	23.8	<1
14	Packaging fresh and chopped vegetables	30	40.3	<1
15	Dried vegetables packaging	34	39.9	<1

Source: Findings of the study, GBP, 2011.

5.2.3 Recommendations to decision-makers

The following suggestions and policies emerging from the results of the field study may help prevent or decrease the destructive impacts of drought and unemployment.

- Promote the participation of farmers.
- Income generation in non-farm activities.
- Use institutional and non-institutional activities, shifting the position of crisis in unemployment to an equilibrium situation.
- Strengthen the role of rural people and local organizations.

- Prepare an applied pattern for managing unemployment.
- Reduce the costs of production.
- Investment in the establishment of small food processing industries.
- Payment of agricultural credits.
- Cultural reform in capital utilization by introducing an optimal pattern.
- Prepare the groundwork for new jobs.
- More supervision on accomplishing employment projects.
- Government financial supports of income generation and job diversification.
- Investment in infrastructures (i.e. rural roads, electricity and canals).
- Training and promotion of optimal and efficient jobs.
- Empower local collaborations such as micro-finance.
- Diversification of credit sources for farmers.
- Increase access to necessary information at the national and village level.
- Establish an organization to study vulnerability during crisis.

5.2.4 Some of the limitations and constraints of the study area

- Water shortages for agricultural activities
- High unemployment rate
- Lack of industrial activities
- Lack of bank credits and warranties
- Lack of paved farm roads
- Scarcity of capital
- Shortages of sport and training facilities
- Lack of agricultural commodities and coope-ratives
- Inadequate facilities and services
- Price fluctuation of agricultural products
- High production costs
- Drought
- Inappropriate agricultural marketing

6. Monitoring of range and forest plants biodiversity of Gareh Bygone Plain in Fars province

6.1 Introduction

Desertification annually puts millions of hectares of economically important ecosystems out of production. Desertification control through spate irrigation (SI) is a sustainable method for the management of marginal drylands.

This study was implemented at the Kowsar Floodwater Spreading and Aquifer Management Research, Training and Extension Station in the GBP from 2009 through 2012. Temporal and spatial variations of precipitation in this plain are very high, and although the climate follows the Mediterranean regime, flood-producing thunderstorms may occur at any time of the year.

6.2 Methodology

The presence, population density, crown cover and yield of the plants were determined in the BZ1 and BZ4 artificial recharge of groundwater (ARG) systems (treated), and on an area not receiving floodwater (control) on 10 × 1m² temporary plots established at random, and on 150 m transects (Fig.1). The sampling method was random, employing the systematic method. The percentage area covered by grasses, forbs, shrubs and litter, gravel and bare soil was determined using a 1m² frame with a 10 × 10 grid. All grasses and forbs in the 100 plots were clipped to 1cm height and air-dried to attain a constant weight. The current year's shrub was also sheared and dried as before.

6.3 Results

The mean number of rainy days, number of floods, annual rainfall, population density, yield, crown cover percentage, and presence or absence of plant species in the ARG systems and control plots are presented in Tables 2–4.

TABLE 2.
AVERAGE OF NUMBER OF RAINY DAYS, NUMBER OF FLOODS, AND ANNUAL RAINFALL DURING THE STUDY PERIOD

Year	Number of rainy days	Number of Floods	Precipitation mm
2009-2010	14	1	145.5
2010-2011	22	3	181.0
2011-2012	23	4	246.5
2012-2013	18	5	124
Average	19.5	3.35	174.25

Source: Findings of the study, GBP, 2011.

TABLE 3.
MEAN SOIL COVER, DENSITY AND YIELD OF THE SI AND CONTROL IN 2009–2012

Site	Year	Cover plant %	Litter %	Gravel %	Soil bare %	Density n/m²	Yield (kg/ha)
BZ_1	2009	26.69	11.48	0.08	61.76	1.82	156.59
	2010	26.9	11.49	0.07	61.54	2.03	188.24
	2011	26.82	17.40	0.14	55.64	2.73	171.02
	2012	22.42	22.65	0.12	56.68	2.22	196.54
	Mean	25.71	15.76	0.10	58.91	2.20	178.10
BZ_4	2009	6.82	57.97	0.00	35.21	0.05	110.70
	2010	6.89	57.90	0.00	35.21	0.23	132.84
	2011	15.56	48.88	0.00	35.55	0.13	212.03
	2012	36.33	55.73	0.00	8.13	0.13	699.17
	Mean	16.40	55.10	0.00	28.50	0.10	288.70
Control	2009	16.90	5.10	0.08	77.92	0.18	127.10
	2010	17.00	5.10	0.08	77.82	1.30	127.1
	2011	21.30	1.30	0.14	71.20	0.90	157.9
	2012	21.50	11.10	0.20	73.70	1.00	117.72
	Mean	19.18	5.65	0.13	75.16	0.85	132.46

Source: Findings of the study, GBP, 2011.

6.4 Discussion

Contrary to the findings in the USA (Vallentine, 1971), no unresponsive species to spate irrigation were observed, and were classified into the two following categories:

Species thriving with SI include annual grasses and *Helianthemum lipii* (L.) Pers. in the BZ_1 system. and *Phalaris minor* Retz., *Lolium sp*.L., *Poa bulbosa* L., *Cynodon dactylon* (L.)Pers., *Hordeum marinum* Hudson, *Bromus danthoniae* Trin., *Aegilops triuncialis* L., *Avena fatua* L., *Alhagi camelorum* Fisch, *Aegilops cerasa* Boiss., and *Carex stenophylla* L.

Species that were negatively affected by SI and/or eliminated include *Madicago spp., Stipa capensis* Thunb., *Stipagrostis plumose* (L.) Munro ex T.Anders, *Astragalus squarrosus* Burge., *Acantolimon sp*. Boiss., *Dendrostellera lessertii* (Wikstr.) Van Tiyeh., *Artemisia sieberi* Besser., and *Anisosciadium orientale* DC.

As expected, irrigated plants were more vigorous, taller, and had larger crown cover than control plants. The density of annual medics was lower in the upper strips where sediments covered their seeds more than in the lower strips. *Helianthemum lipii* (L.) Pers. and *Dendrostellera lessertii* (Wikstr.) VanTiyeh. have thrived well in BZ_1, however, they have decreased in BZ_4. As the latter system receives more water and sediment than BZ_1, it cannot be known which factor is more important in their negative reaction to SI. As BZ_4 is planted to *Eucalyptus camaldulensis* Dehnh., shading and/or allelopathy may also be responsible for the observed negative response.

It should be noted that the composition of plants in the SI systems constantly changed as a result of the introduction of seeds carried in floodwater or brought by different means; a comparison of Tables 3 and 4 illustrates this claim. We have detected 57 species in the SI systems and 43 species in the control. Thus,

TABLE 4.
LIST OF THE GENERA AND SPECIES FOUND IN THE RESEARCH PLOTS

No	Name	CO	SI	No.	Name	CO	SI
1	*Acantolimon* sp. Boiss.	*	*	33	*Helianthemum lippii* (L.) Pers.	*	*
2	*Achillea eriophora* Dc.	*	*	34	*Hordeum marinum* Hudson.	*	*
3	*Aegilops cerasa* Boiss.	-	*	35	*Launea acanthodes* (Boiss.) O. Kuntze	-	*
4	*Aegilops triuncialis* L.	*	*	36	*Malva sylvestris* L.	-	*
5	*Alhagi camelorum* Fisch.	*	*	37	*Medicago polymorpha* L.	*	*
6	*Allium* sp. L.	*	*	38	*Medicago radiata* L.	*	*
7	*Amygdalus lycioides* Spach.	-	*	39	*Noaea mucronata* (Forsk.) Aschers et Schweivf	*	*
8	*Anisosciadium orientale* Dc.	*	*	40	*Onopordon* sp.L.	*	*
9	*Artemisia sieberi* Besser.	*	*	41	*Orobanche* sp. L.	-	*
10	*Astragalus meridionalis* Bunge Sh.	-	*	42	*Peganum harmala* L.	*	*
11	*Astragalus onobrychis* L.	-	*	43	*Pennisetum* sp. Rich.	*	*
12	*Astragalus* sp. L.	*	*	44	*Phalaris minor* Retz.	-	*
13	*Astragalus* sp. L.	*	*	45	*Pimpinella* sp. L.	*	*
14	*Astragalus squarrosus* Burge.	*	-	46	*Poa bulbosa* L.	*	*
15	*Atriplex leucoclada* (Boiss.) Aellen	*	*	47	*Prosopis farcta* (Banks and Soland.) Machr	*	*
16	*Avena fatua* L.	*	*	48	*Pteropyrum aucheri* Jaub and spach	*	*
17	*Bromus danthoniae* Trin.	*	*	49	*Salsola* sp. L.	-	*
18	*Bromus* sp. L.	*	*	50	*Scariola orientalis* (Boiss.) Sojak	*	*
19	*Carex stenophylla* L.	*	*	51	*Stellaria media* (L.) Cyr.	-	*
20	*Carthamus oxyacantha* M.B.	-	*	52	*Stipa capensis* Thunb.	*	*
21	*Cenchrus ciliaris* L.	-	*	53	*Stipagrostis plumose* (L.) Munro ex T. Anders	*	*
22	*Centaurea behen* L.	*	*	54	*Teucrium polium* L.	*	*
23	*Convolvulus acathocladus* Bioss	-	*	55	*Trigonella* sp. L.	*	*
24	*Convolvulus* sp. L.	*	*	56	*Turgenia latifolia* (L.) Hoffm.	-	*
25	*Cymbopogon olivieri* (Boiss.) Bor.	*	-	57	*Vicia* sp. L.	-	*
26	*Cynodon dactylon* (L.) Pers.	*	*	58	*Ziziphora teniur* L.	-	*
27	*Dendrostellera lessertii* (Wikstr.) VanTiyeh.	*	*	59	*Ziziphus nummularia* (Burm.F.) Wiyhth and Arn.	*	*
28	*Ebenus stellata* Boiss.	*	*				
29	*Echinops* sp. L.	*	*				
30	*Ephedra foliate* Boiss. and Kotschy	*	*				
31	*Gundelia tournefortii* L.	*	*				
32	*Haplophyllum* sp. A. Juss.	*	*				

Source: Findings of the study, GBP, 2011.

14 species are apparently new to the site. However, there are 2 species [*Astragalus squarrosus* Burge., and *Cymbopogon olivieri* (Boiss.) Bor]. in the control, which had been eliminated in the SI systems.

TABLE 5.
FREQUENCY OF PLANTS IN THE SPATE IRRIGATED AND CONTROL PLOTS

Parameters	BZ_1		Control	
	Quantity	%	Quantity	%
Frequency of plants in a plot	57	100	43	100
Frequency of annual species in a plot	21	36.84	36	74.41
Frequency of perennial species in a plot	36	63.16	11	25.59

Source: Findings of the study, GBP, 2011.

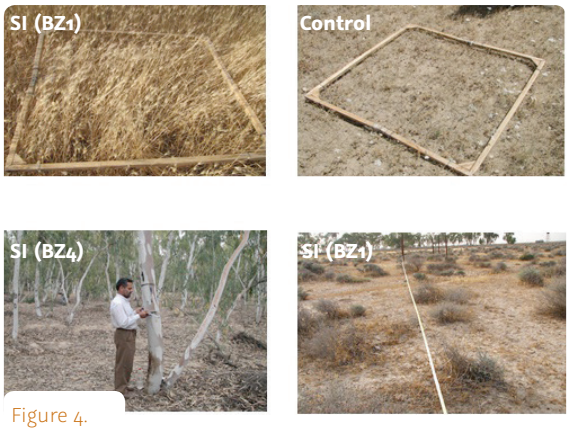

Figure 4.
Plant species identification in spate irrigation (SI) and control sites. © Sayyed Hamid Mesbah, FRCANR, 2011. Research findings, GBP

7. Feasibility of producing organic honey from Kowsar floodwater spreading system in Gareh Bygone Plain

Water scarcity is the main reason the inhabitants of Gareh Bygone Plain abandoned agriculture and migrated from the region to cities with little or no employment opportunities. Beekeeping can be one way by which inhabitants of this region can generate income.

The Kowsar Floodwater Spreading Research Station (FWS) was established within a 192 km² basin in a sandy desert in Gareh Bygone Plain in southwest Iran. Following 26 years of FWS activities, an artificial ecosystem has been created, and soil properties, particularly water retention characteristics and vegetation cover, have significantly improved. Certain species of Acacia and Eucalyptus trees were planted in this station such as *E. camaldulensis*, *E. microtheca*, *E. gillii*, *E. intertexta*, *E. oleosea*, *A. victoria*, and *A. salicina*, as they can adapt to the environmental conditions of the plain. The various species of Eucalyptus and Acacia planted in the Kowsar floodwater spreading system flower in a 12-month season, providing enough nectar and pollen for honeybees throughout the year.

In order for honey to be certified organic, the beehives must be placed in isolated areas miles from the dense population, industry, traffic congestion, and farm fields treated with chemicals and landfills. In addition, a bee's flying range is determined by their natural instinct, which tells them to stay within their natural four-mile range from the hive location. Finding an area that can be certified as organic is

difficult, and the reason there's so little certified organic honey on the market. These regions are a rich source of wild vegetation, producing some of the finest honey in the world. The United States Department of Agriculture (USDA) and Canadian Organic Certification impose a rigorous set of standards and conditions that must be adhered to by both the producer (beekeeper) and the packager. All aspects of honey production, including the source of the nectar, the forage area of the bees, management of the bees, the extracting process, and transportation are taken into account in the certification process.

The main objective of this study is to investigate the production of organic honey in a Eucalyptus plantation in the Gareh Bygone Plain. At the beginning of February 2011, twenty honeybee colonies of *Apis mellifera* L. were bought, standardized and reared with special care. The bees were not fed sugar syrup and did not receive any synthetic chemical substances. The honey contained in the beehives was completely extracted at the end of February. At that time, some species of Acacia and Eucalyptus were in flower, and the colonies foraged on the nectar and pollen from February until early April. Again, at the beginning of the April 2011, the total honey from the colonies was extracted and queen excluders were placed on top of the hive body. A shallow super was placed on the top of the queen excluder to gather the extra honey. The dominant plant species at the project site is *E. camaldulensis*, and the best foraging took place during May to June when this tree was in flower. Honey samples for chemical analysis were collected at the end of May. The results show that these samples have the standards of organic honey. In general, it seems that there is a high potential for organic honey production in Gareh Bygone Plain and consequently it can be an important alternative income for farmers and local cooperatives, especially during drought conditions.

8. Empowering local organizations to participate in aquifer management in the Gareh Bygone Plain

8.1 Introduction

One of the oft-cited reasons for the failure of development projects in developing countries is a lack of effective participation. It is likely that this endeavour in the Gareh Bygone Plain will empower the different groups of people, especially the underprivileged through the establishment of a non-governmental organization (NGO), consisting of four cooperatives. The research techniques include Participatory Rural Appraisal (PRA), surveys and field research. To empower local people in the Gareh Bygone region, five PRA workshops were held during 2009–2011 in the four villages. The problems of the rural population – the groundwater situation and the context of social capital – were discussed and analysed in these workshops. In order to empower local people and farmers, twelve orientation sessions and educational workshops were held in the Gareh Bygone villages. In this field research based on Cochran's sampling formula, with 400 households in the four villages, 15 per cent of the households (60 households) were selected for the statistical analysis. The number of questionnaires depended on the population of each village.

8.2 Findings of the study

Water is the most basic need of the area: Establishment of the Kowsar Station in the plain, while striving to harvest as much floodwater as is environmentally

safe and financially viable was the answer to this pressing problem. However, as over-pumping and prolonged droughts diminished groundwater resources, the area is facing a water crisis. Therefore, when respondents were asked, 'If the government offers to solve your most important problem what do you suggest?', about 70 per cent replied that an improvement in the drinking water was vital.

Mobilization through cooperative formation: It can be concluded that the local population have somewhat accepted the fact that cooperation is the key to a better life. The creation of the four cooperatives has therefore been deemed beneficial. However, as the current prolonged drought and the general budgetary constraints have lowered the financial rewards, their practical benefits have not been well defined, suggesting that it will take a drastic change in the current situation to make believers of the cooperative members.

Positive assessment of people on the cooperatives: Despite the poor performance of these cooperatives, the majority of locals support them believing that if they were presented with a roadmap with financial rewards, they would be willing to cooperate and participate in such projects. The most important bottlenecks to the growth of these organizations are capital shortage and a lack of government support.

Reinforcement of the Kowsar Station activities through cooperatives: The ignorance of a minority had caused a conflict of interest between the cooperatives and the station. A very distinct advantage of cooperatives has been a change in the locals' impression of the services rendered to the community in the past 30 years. The surveys show that some 70 per cent of residents approve the station's activities. However, they rightly insist that they should be consulted in the station's affairs and that some of the tasks should be delegated to the cooperatives.

The necessity of empowerment through offering training courses: 'Knowledge is wealth' and this adage perfectly applies to the inhabitants of the plain. A rather low literacy rate and a lack of understanding of ecology have shown the urgent need to hold orientation and training courses for this rural community. So far, only 20 per cent of respondents have been able to participate in such courses. Nonetheless, it is encouraging to report that the majority of the respondents have evaluated these courses as useful.

8.3 Recommendations (practical implications in a nutshell)

The gist of this report may be presented in two words: water and money!

The following points have been suggested as being the most important by the cooperatives:

1. Training members of the cooperatives on efficient methods of domestic freshwater utilization.

2. Training members of the cooperatives on water use optimization at the farm level, i.e. the installation and efficient operation of modern irrigation systems.

3. Assisting the cooperatives in securing low interest loans in order to install more efficient pumping stations.

4. Planting fruit trees in the Aquitania project site adjacent to Ahmad Abad village, providing that the feasibility study approves this alternative.

5. Contracting some of the Kowsar Station's activities to the cooperatives. This would encourage private

investment and a genuine concern for the growth, maintenance and protection of the station.

9. The effect of floodwater irrigation on the performance of jojoba *(Simmondsia chinensis)* in the Gareh Bygone Plain

9.1 Introduction

Simmondsia chinensis (Link) C. K. Schneid., commonly known as jojoba, is a dioecious evergreen shrub native to the dry regions of southwest United States and northern Mexico. This species is very tolerant of drought and heat, and is of great importance in terms of soil conservation and combating desertification. Moreover, it produces seeds containing about 50 per cent liquid wax – a unique substance of high potential value in cosmetics, food, pharmaceuticals, plastics, polishes and candles, as well as in heavy industry for the lubrication of moving parts under high temperatures.

As jojoba is a low water demand species that produces a very valuable oil, it is assumed to have the potential to improve the future livelihood of the inhabitants of Gareh Bygone Plain, as certain ecological features of the plain are similar to those of jojoba's native habitat. The weather of the plain is characterized by a sub-Mediterranean climate with the rainy season beginning in November and ending in March, followed by a very long hot season. The average annual rainfall of the plain is about 200 mm. The temperatures are very high in the summer and can reach 46°C in July. Temperatures below zero rarely occur from late November to mid-February with very low humidity throughout the year. The altitude of the planting site is 1100 m above sea level.

The soil is light, sandy and very deep, and is not saline, while the organic matter of the soil is very low. The plain is originally a range area, consisting of mostly annuals and several perennial bushes with scattered individuals of *Ziziphus nummularia*. However, many farmers have converted large areas of rangeland to the cultivation of cereals and summer crops in particular. This process was much accelerated following a sharp increase in groundwater, as a result of flood irrigation. For this reason, resources of good quality water are nearly exhausted, especially after several years of severe droughts. Hence, the sharp interest in using drought resistant species, particularly those with valuable production.

9.2 Projects activities

The study was conducted so as to investigate the adaptation and performance of jojoba species under rainfed and floodwater irrigated conditions. The selected site comprised of two adjacent locations: a high ground, the rainfed treatment area (control); and a low ground, which may potentially be irrigated, even with a meagre amount of floodwater. In late February 2008, a total of 267 two-year-old potted jojoba seedlings were planted by 2x3 m spacing in a randomized statistical design, of which 147 seedlings were rainfed and 120 seedlings were flood irrigated. The average height of the seedlings just before planting was 24 cm. The seedlings had been propagated from seeds collected from a jojoba orchard in Jahrom, 40 km southwest of the Gareh Bygone plain. All plants were irrigated once every 15 days in the dry season of the first year to help their establishment. Growth assessments (seedling height,

number of stems, crown diameter, phenological factors, including flowering, sex differentiation, and so on) were monitored on several occasions every year, and the final assessments were made in early January 2013.

9.3 Results and discussion

9.3.1 Survival and growth

The survival of seedlings in the rainfed plot after 5 years was 77.5%. The average height and crown diameter of all seedlings was 81.08 cm and 80.25 cm, respectively. The average number of stems and shoots above a collar height of 10 cm of all the seedlings was 19.13.

The plants in the low area (flood irrigated) did not perform well and most died despite receiving some floodwater several times during 2009 and 2011. This unexpected result may be due to waterlogging, showing that this species is unable to tolerate such conditions, which is in keeping with results from other experiments in Fars province.

9.3.2 Vegetative growth

Vegetative activity reached its peak in March and April, and increased again in October but to a lesser degree. The autumn growth was particularly associated with new twig growth.

9.3.3 Flowering and sex differentiation

Most of the seedlings differentiated during the fourth year. Males apparently tended towards more rapid and vigorous growth and earlier maturity. In females, differentiation occurred mainly later in the winter season and largely after the male flowering period. Flowering female plants rarely produced any fruit in the third and fourth year.

The final sex ratio was about 41% male and 37% female, and 21% did not reach the stage of bud break and sex differentiation after 5 years. The behaviour of male and female plants was very similar, however, the setting of floral buds and growth in female plants lasts longer than in males. Flowering took place over quite a long period from mid-January to mid-March and varied from plant to plant. It is known that the yield is directly associated with the vegetative activity of the plant.

9.3.4 Fruit ripening

Fruiting started in the fourth year. The fruits did not ripen simultaneously either on the same plant or on different individuals. For the most part, one harvest in summer between mid-June and mid-July was potentially possible.

9.3.5 Yield

Jojoba yield starts at least after 6–7 years of planting. In this experiment, it was not possible to evaluate and report on the amount of yield, because the quantity of seed production was too small to make any economic assessments, although a few plants started yielding at the age of five. Yield is an individual characteristic and varies from plant-to-plant and from year-to-year, and it known to be affected by environmental fluctuations.

9.4 Conclusions and recommendations

It can be concluded that in general jojoba demonstrated a relatively acceptable adaptation to the Gareh Bygone Plain in terms of survival in rainfed conditions. The growth performance was also relatively fair, but not particularly satisfactory. Having reached the stage of seed production, the species met the criteria for an acceptable adaptation to the

plain. However, severe climatic factors, including exceptional high temperatures as well as very low annual rainfalls during the last four years, were responsible for a relatively low growth.

The results showed that jojoba can grow and adapt in the Gareh Bygone plain and similar habitats. However, it is too early to recommend any commercial plantations until more experiments have been carried out in terms of comparisons between provenances and clones, especially under several edaphic conditions and the application of some irrigation treatments.

Jojoba starts yielding in the fifth year after transplanting. It can develop and produce in sandy soil under a winter rainfall of about 200 mm/year and a climate almost free of frost.

It must be emphasized that the adaptation of a nearly wild species and bringing it to cultivation is an expensive, prolonged and uncertain process. The cultivation and improvement of any new crop involves a long and expensive process of research and experiments. The intrinsic value of jojoba lies in its liquid wax.

To reproduce the characteristics of outstanding plant types, vegetative propagation is essential. However, according to the results obtained from other experiments in Fars province, it is more reasonable to use seedlings rather than cuttings in these arid and harsh environments and under non-irrigated conditions, as seedlings may produce deeper root systems compared to vegetative propagated plants.

Figure 5.
The performance of jojoba. © Morteza Mortazavi, FRCANR, 2011.

10. Effects of the Sowbug (*Hemilepistus shirazi* Schuttz) on desertification control in Gareh Bygone Plain

10.1 Introduction

The appearance of sowbugs (*Hemilepistus shirazi* Schuttz) in the sedimentation basins of the artificial recharge of groundwater (ARG) systems in the Gareh Bygone Plain (GBP) in southern Iran is considered an ecological breakthrough in desertification control. The main function of the sowbug lies in its ability to puncture the hard crust, facilitating rapid percolation of recharge water. Moreover, since this crustacean was a welcome addition to the research site, it was hypothesized that it could start a completely new life cycle in the area. Preliminary investigation of the

burrows indicated the presence of a vertical shaft, 30-40 cm deep in each.

This organism is a crustacean that is 10-15-mm long and 5-mm wide. It is blackish grey and has 7 pairs of legs (Fig. 6a). Sowbugs live in damp places, forage on vegetation, and digest the soil organic matter. Their burrows, 7 mm in diameter and up to 80 cm deep, serve to aerate and drain the soil profile. They are very active in the spring and autumn, coming out of their burrows in the cool air of early morning and late afternoon. It seems that digging deep into the soil is a strategy to reach more humid surroundings. With their mandibles, they form semi-cylindrical rods of soil that are 2 mm long and 1 mm in diameter, placing them to one side of the opening of their burrows (Fig. 6b).

Figure 6.
(a) A dorsal view of a female *Hemilepistus shirazi*
(b) Schuttz parallelepiped-shaped burrowed material

10.2 Materials and methods

The study was performed at the Kowsar Floodwater Spreading and Aquifer Management Research, Training and Extension Station in the Gareh Bygone Plain, 200 km to the SE of Shiraz on the debris cone of the Bisheh Zard River. Eight ARG systems, covering a total area of 1,365 ha were installed during 1983–1988. More details may be found elsewhere (Kowsar, 1991, 1998).

To characterize some of the physico-chemical properties of the sowbug's burrowed materials, the BZ1 system was selected. The system on which this search was conducted was the first in a series of eight systems constructed in Gareh Bygone Plain since 1983. This system comprises six sedimentation basins. The second sedimentation basin of this system was chosen, as sowbugs were very active there. About 2 kg of the rod shaped soil (burrowed material) was collected from 70 sowbug infested plots (10–20 g adjacent to each opening). Chi-square test was used to compare the physicochemical properties of the burrowed materials and the freshly laid sediment (control). Infiltrability of 11 paired plots (with and without the sowbug burrows) was determined using the double ring method (Anon, 1990), in one of the floodwater spreading systems, which was designed and constructed in 1983. The infiltration rate of every plot was measured for each pair of plots during the same day. The most common method used for aggregate stability measurement is wet sieving. To determine the aggregate size distribution, soil samples were dried and then sieved through a set of sieves of various sizes (8.0, 4.75, 2.8, 2.0, 1.0, 0.8, 0.3 and <0.3 mm). Weights of aggregate remaining on each sieve were used to determine aggregate size distribution.

10.3 Findings of the study

Table 1 presents the result of some physicochemical analyses performed on the samples from the burrows (treated), and on the surface soil of the adjacent plots (control). It is confidently claimed that most elements, except calcium carbonate, as well as pH is greater than from freshly laid sedimentation (control), showing a significant difference by 1%. The results of the analysed burrowed materials and freshly laid sediment are presented in Table 1. The burrowed material was highly concentrated in organic C, macro- and microelements. The pH was lowered by

1.4 units in the same material. Cautious introduction of plants attractive to this useful organism is an environmentally sound and a financially viable method of lengthening the economic life of the artificial recharge of the groundwater system. Floodwater spreading in Gareh Bygone Plain provides good habitat conditions for the sowbugs. The invasion of the sowbugs to the ARG systems in the Gareh Bygone Plain in 1993 changed the scenario. These crustaceans, which can sometimes make 10 burrows per m^2 at a depth of 185 cm, increase infiltration rates 4.2 fold in some plots, and 2.5 fold on average. Results show that the mean aggregate stability percentage for the control (without sowbugs) is 26.14%, while for burrowed materials (with sowbug) it is 78%. The aggregate stability percentage of burrowed materials is 3 times more than the control. The weighted mean of diameter for burrowed materials of sowbug is 1.86 gr, and 0.44 gr for the control. The measure of soil aggregate stability becomes important because it can provide general information about soil condition. Information on soil aggregate stability can also improve programmes that are adapted to the specific soil type and crop demands.

10.4 Conclusion

Extending the economic life of the artificial recharge of groundwater systems is a challenge to the planners and implementers of these facilities. The surface geology of most of our flood-producing watersheds makes their runoff highly turbid, meaning that very large sedimentation basins have to be incorporated into the design. However, the presence of very fine particles, particularly clay minerals such as chlorite, palygorskite and smectite cause rapid clogging of the basins and infiltration ponds. Although root channels enhance percolation, infiltration of the basins and ponds is greatly decreased by crust formation.

Sowbug burrowing is beneficial in that it improves the soil's physical conditions and thus plant growth, allowing air and water penetration into the soil. The burrowed materials and castings resist erosion more than the freshly laid sediment from which they are formed. Sowbug activity also improves the chemical properties of soil, making it more fertile. They increase the soil's organic carbon content, which plays a key role in soil productivity and environmental quality. The higher organic carbon in the burrowed material, compared with the original soil and the freshly laid sediment, represents a potential for carbon sequestration when viewed as a long-term management system. It also increases micronutrient content in the soil, which is very important in arid and semi-arid regions. These crustaceans increase infiltration rates by up to 4 times, and because they feed on quail bush, it seems prudent to introduce this browse plant into the systems, even for the sole purpose of attracting the sowbugs. Needless to say, this plant can support four sheep all year round if planted at a density of 625 bushes ha^{-1} – quite a feat for a sandy desert. Domestication of this organism, a token of the ARG systems, seems technically practicable, environmentally sound, economically feasible and socially acceptable.

11. Spate irrigation barley trail (tropy variety) in Gareh Bygone Plain

11.1 Introduction

Water shortage is the most limiting constraint in the drylands. While the mean annual rainfall in drylands is very low, its variability is extremely high (erratic in terms of distribution and frequency). The chance of receiving the desired rainfall at the expected time is meagre, making water the most limiting constraint in arid zones and thus the most precious commodity, with floodwater the largest supplier in drylands. Although floodwater is renewable, its use must be optimized. Spate irrigation is a form of water management that is unique to semi-arid environments, which is found in the Middle East, North Africa, East Africa, West Asia and parts of Latin America. Floodwater spreading for spate irrigation and the artificial recharge of groundwater (ARG) is indigenous knowledge that has been practiced for millennia in different parts of Iran. It is important to appreciate that aquifer management, a paradigm based technology, is more than just simply raising the water table.

11.2 Methodology

The Kowsar Floodwater Spreading, Aquifer Management, Training and Extension Station is located in the Gareh Bygone Plain (GBP), 190 km to the southeast of Shiraz. Each ARG system consists of an inundation canal that diverts floodwater to the command area. A stilling basin, called a conveyor-spreading channel (0.27-7.30 km in length) spreads the water as a thin, non-erosive sheet over the head of the first sedimentation basin. For this research, a one hectare plot in the floodwater spreading system (trial plot) and another hectare from the floodwater spreading system (control plot) have been selected for the cultivation of barley in December 2009. In order to determine soil moisture content and soil fertility before cultivation in each plot, three soil samples were taken from the soil surface at a depth of 0 to 30 cm. 200 kg/ha of seed of the tropy variety was provided by Darab Agricultural Research Station and its seed viability and percentage purity were determined. Following the preparation of the planting sites with the low tillage method, plots were divided into 6 equal subplots (40 m length and 20 m width in the direction of flood spreading). After the first rainfall and floodwater spreading (7 December), barley seeds were cultivated in sub-plots. Fertilizer was used to the amount of 100 kg/ha in 27 February 2010. During the growth period of barley, floodwater was not made available for spreading on the trial plot. Thus, planted barley only received moisture from rainfall. In the beginning and the final stage of growth, the length and height of the barley cluster, seed and straw yields were measured and recorded for both plots. Fertilizer was given to the subplots (8 kg N for each subplot). During the period of growth, the necessary data was recorded.

11.3 Findings of the study

The soil moisture content in the trial plot is higher than the soil moisture content in the control plot due to the floodwater spreading in the trail plot before the cultivation of barley. Additionally, soil fertility in the trail plot is much higher than in the control plot due to the spread of rich floodwater on the trial plot in the past. The barley yield in trial plot is twice that registered in the control plot (Table 1) because soil fertility and moisture storage is higher in the trial plot than in the control.

TABLE 5.
FREQUENCY OF PLANTS IN THE SPATE-IRRIGATED AND CONTROL PLOTS

Parameters	BZ,		Control	
	Quantity	%	Quantity	%
Frequency of plants in a plot	57	100	43	100
Frequency of annual species in a plot	21	36.84	36	74.41
Frequency of perennial species in a plot	36	63.16	11	25.59

Source: Findings of the study, GBP, 2011.

11.4 Preliminary results obtained

Low and erratic rainfall is the most limiting constraint in GBP. Spate irrigation can be used in floodwater spreading systems in the approximately 500 hectares in GBP plain. Spate irrigation can produce fairly good yields, but is not without technical and administrative constraints. The best time to irrigate and sow barely in GBP is from 10 November to 10 December. Of course this would depend on rainfall and floodwater. Nine days is the best length of time for land preparation after flooding, while four days is considered the best for land preparation after rainfall. A prolonged period of time results in water loss by evaporation. In 2010, floodwater was not spread on the farms and irrigation relied solely on rainfall. Nevertheless, the total weight of barley seed and straw in the trial plot in the floodwater spreading system was 1,616.27 kg, and was 820.83 kg in the control plot outside the floodwater spreading system. This significant difference in yields can be related to higher soil fertility and moisture storage in soil profiles in the trial plot.

11.5 Preliminary recommendations

Further floodwater spreading and barley cultivation in the future is needed for more accurate results.

12. Research institution and team composition

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13. National workshops on SUMAMAD

12.1 Objectives

The main objectives of these workshops were: a) to review the achievements of the SUMAMAD Phase II sub-projects during 2009 to 2013; b) to discuss scientific papers related to the drylands of Iran (drought, management of drylands, groundwater degradation, human security, social and economical impacts); and c) to visit the projects in the Gareh Bygone Plain and understand the issues under investigation. These workshops were organized by the Research Society for Sustainable Rehabilitation of Drylands (REaSSURED) in cooperation with the Fars Research Center for Agriculture and Natural Resources.

14. Publications as a result of SUMAMAD

Chabokrow, Gh. R. 2011. *Alternative income-generating activities in Gareh Bygone Plain*. In: Proceedings of the National Workshop Sustainable Management of Marginal Drylands (SUMAMAD) Kowsar Research Station, Gareh Bygone, Fasa. 31 Oct. 2011.

Mesbah, S.H. 2010. *Rehabiliation of range plants with flood water spreading system*. In: Proceedings of the National Workshop Sustainable Management of Marginal Drylands (SUMAMAD) Kowsar Research Station, Gareh Bygone, Fasa. 6 Oct. 2010.

14. References

Anon. 1990. A manual for measuring infiltration rate using double-ring. Power Ministry. Fars Regional Water Organization. 19 p. [in Farsi].

Ghahari, G.R., M. Pakparvar, D. Gabriels, S.A.Kowsar, 2009. Effect of discharge on time efficiency of aquifer recharge of groundwater resources in Gareh Bygone Plain. *Water Management Journal*, Vol. 1, No. 1, pp. 75–95.

Kowsar, S. A. 1991. Floodwater spreading for desertification control: An integrated approach. *Journal of Desertification Control Bulletin,* UNEP, Vol. 19, pp. 3–18.

Kowsar, S. A. 1998. Aquifer management: A key to food security in the deserts of the Islamic Republic of Iran. *Journal of Desertification Control Bulletin,* UNEP, Vol. 33, pp. 24–28.

Pakparvar, M., Hashemi, H., 2010. Physical Properties of the Vadose Zone at the Kowsar Station, Gareh Bygone, Fasa. In: Proceedings of the National Workshop Sustainable Management of Marginal Drylands (SUMAMAD), Kowsar Research Station, Gareh Bygone, Fasa. pp.107–121.

Pakparvar, M., 2010. Floodwater spreading on undulating terrains: Snags and solutions Case study: The Galehdar Project. In: Proceedings of the National Workshop Sustainable Management of Marginal Drylands (SUMAMAD), Kowsar Research Station, Gareh Bygone, Fasa. pp.176–187.

Vallentine, J.F. 1971. *Range development and improvements*. Brigham Young University press, provo, UT. 516p.

Mesbah, S.H. 2011. *Wood production in flood water spreading system*. In: Proceedings of the National Workshop Sustainable Management of Marginal Drylands (SUMAMAD) Kowsar Research Station, Gareh Bygone. Fasa. 31 Oct. 2011.

Mesbah, S.H. 2012. *Monitoring of range and forest plants biodiversity of Gareh Bygone Plain*. In: Proceedings of The National Workshops Sustainable Management of Marginal Drylands (SUMAMAD) Kowsar Research Station, Gareh Bygone, Fasa. 31 Oct. 2012.

Pakparvar, M. 2007. *Floodwater spreading on undulating terrains: Snags and solutions*. In: Proceedings of the National Workshop Sustainable Management of Marginal Drylands (SUMAMAD) Kowsar Research Station, Gareh Bygone, Fasa. 12–13 Sept. 2006 and 13–14 Aug. 2007.

Pakparvar, M., Gabriels, D., Kowsar, S.A., Cornelis, W., Nekooeian, GH. and Fereidoonian, A. 2011. *Changes in water content of layers in Gareh Bygone aquifer as affected by a flooding event*. Oral presentation: National Workshop on Sustainable Management of Marginal Drylands, Kowsar Research Station, Gareh Bygone, Iran. 31 October 2011 [Full text will be published in workshop proceedings].

Pakparvar, M., Gabriels, D., Cornelis, W., Kowsar, S.A., Edraki, M., Rates, D., and P.S Pereira. 2012. Enhancing of the Remotely Sensed Evapotranspiration in a Multiple Landuse Arid Landscape, Southern Iran. A paper to be submitted to Agricultural Water Management [under review].

Zabatian, Jafar. 2006. *Future of Drylands – An Overview*. In: Proceedings of the Future of Drylands International Scientific Conference, 19–21 June 2006.

Dana Biosphere Reserve

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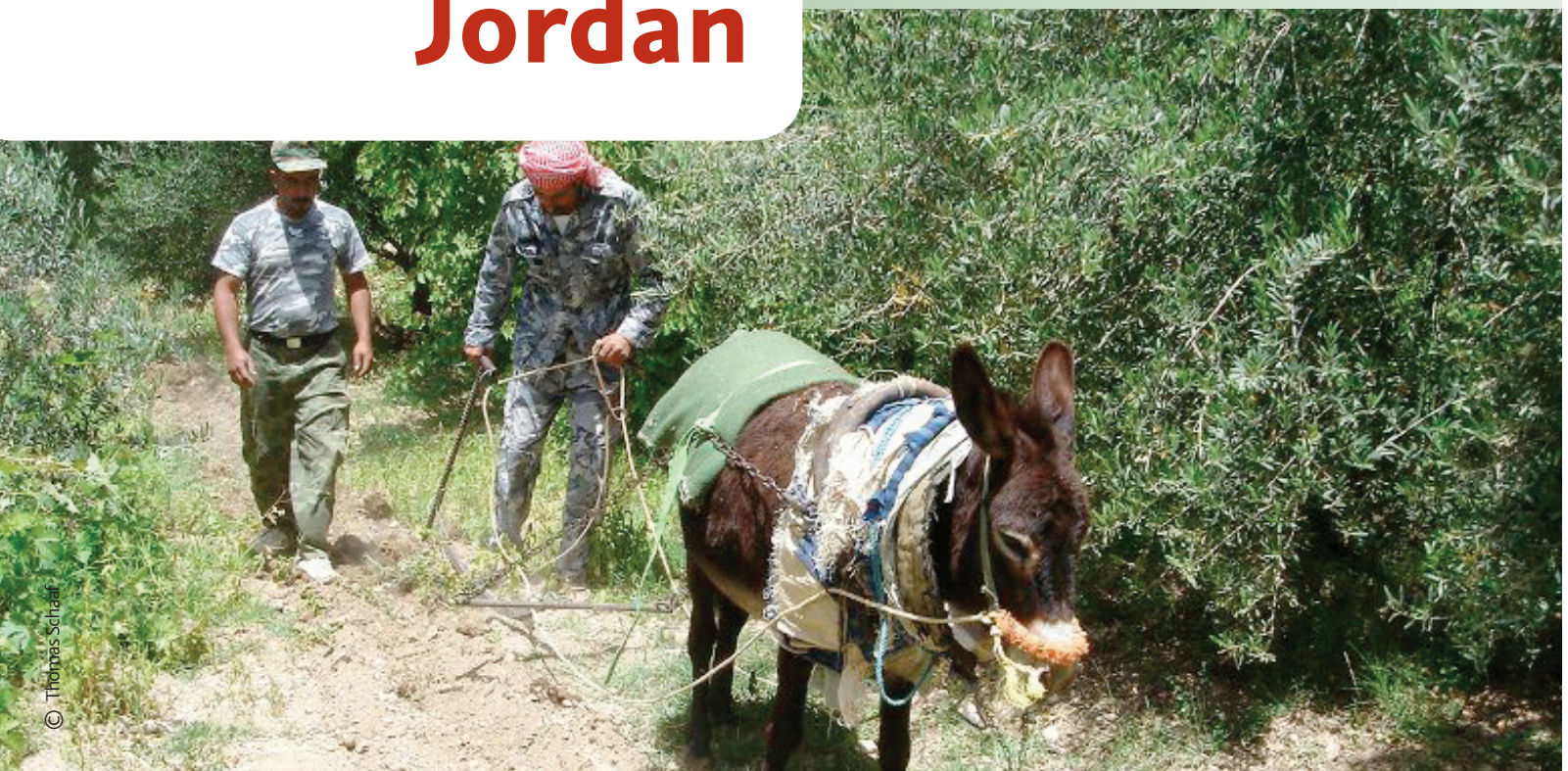

1. Main dryland challenges at the project site

The main dryland challenges at Dana Biosphere Reserve site include:

- The over-exploitation of natural resources from overgrazing, wood collection and hunting.
- The unsustainable use of the drylands: large areas that were previously unsuitable for agriculture are now being used for agriculture.
- The lack of integration between projects and polices from most government agencies in drylands, resulting in a fragmentation of results and efforts.
- The substantial variation in annual rainfall from one year to another makes it difficult to carry out proper land planning owing to a lack of good, long-term databases.
- The shift from the traditional sustainable use of drylands to modern short-term investments, which causes further deterioration of its natural resources through the over-pumping of water, resulting in a further decline in the level of aquifers, increasing soil salinity and the use of chemical fertilizers that leads to more chemical residuals in soil and greater soil erosion.

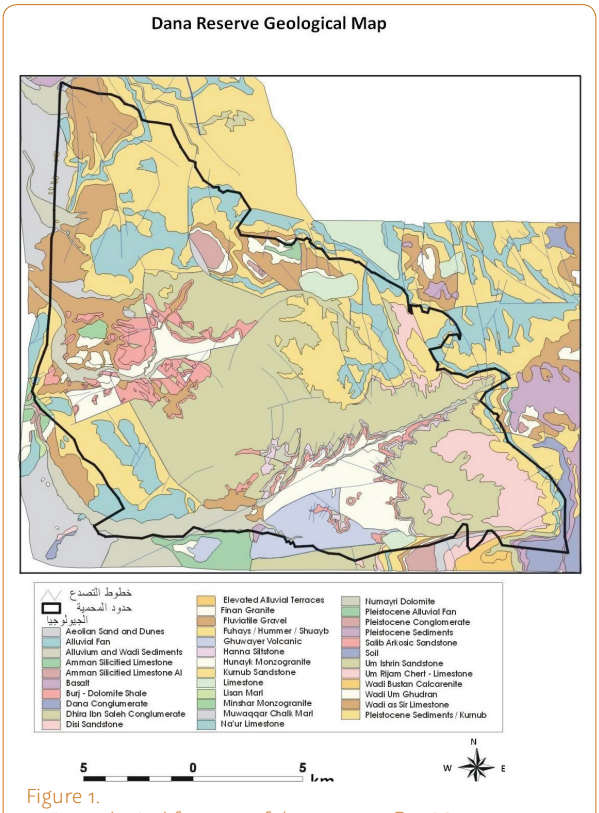

Figure 1.
Main geological features of the reserve. © RSCN

2. Environmental characteristics of the study site

2.1. Climate

The climate in Dana Biosphere Reserve and its surrounding area varies from the eastern highlands, where the altitude reaches 1,600 m above sea level, to the western lowlands where the altitude reaches 100 m below sea level. The climate in the highlands during winter is cold and rainy with temperatures fluctuating between from -10°C to 15°C, with precipitation ranging from 350 mm in good years to 100 mm in dry years.

2.2 Geology and geomorphology

The Biosphere Reserve (BR) is a complex of valley and mountain systems with the Dana Valley the major feature in the reserve. The BR represents a cross-section of the main geological layers and formations in the reserve (Fig. 1). These layers outcrop along the valley and, starting from the lower altitudes, include: Holocene and Pleistocene (1.8 million years) alluvial material; granite and volcanic outcrops; and several layers of the lowermost part of the Cambrian-Ordovician (570 million years) rum sandstone group. In addition, many other valleys traverse the reserve such as Wadi Al Barrah, Wadi Khalid, Mahash, Ratieh and Wadi Ghwebbeh.

2.3 Soil characteristics

The soil type and structure of the 300 km² reserve varies from one area to another with seven different soil types:

1. ***GAR soil:*** has a sandy-sandy clay structure with 80% sand content, an average soil depth of 80 cm and a low content of $CaCO_3$ (calcium carbonate). This type of soil exists at the northern and southwestern areas of the reserve.

2. ***Hay soil:*** is present at altitudes from 300 m to 1,500 m and consists of 35% clay and 15% sand, with the remainder made up of mixed soils and stones. This type of soil exists at the mid- and eastern parts of the reserve.

3. ***TAD soil:*** this soil has 50% of its structure made up of sand; the soil content of gravel and stones increases with depth, reaching 80% at a depth of 50 cm.

4. ***TAW soil:*** its structure is made up of 45% clay and more than 50% lime.

5. ***ARA soil:*** 35% consists of a sandy-lime structure and 35% is made up of stones. It is found at the southwestern part of the reserve.

6. ***TIR soil:*** consists of 35% clay with the rest made up of lime and stones. It is found in the middle of the reserve.

7. ***SWN soil:*** consists of 45% lime with sand, lime and stones found in the western part of the reserve.

2.4 Biotic characteristics

Dana BR represents four of the biogeographical zones that exist in the Middle East, which have their own specific characteristics (Fig. 2), and include:

1. ***The Mediterranean biogeographical zone:*** covers 70 km² (23 per cent of the reserve area), and has an altitude ranging from 800 m to 1,500 m above sea level. This biogeographical zone is considered to have a wealth of biodiversity and contains four vegetation types: juniper vegetation, oak vegetation, steep non-forest vegetation, and water vegetation.

2. ***The Irano-Turanian biogeographical zone:*** covers 68 km² (22 per cent of the reserve area), and has an altitude ranging from 400 m to 800 m above sea level. This biogeographical zone is considered to have the second richest biodiversity and contains two vegetation types: steep vegetation and water vegetation.

3. ***The Sudanian biogeographical zone:*** covers 148 km² (48 per cent of the reserve area), and has an altitude ranging from 100 m to 400 m above sea level. It contains four vegetation types: juniper vegetation, oak vegetation, steep non-forest vegetation, and water vegetation.

4. ***The Saharo-Arabian biogeographical zone:*** covers 20 km² (7% of the reserve area), and has an altitude ranging from 100 m below sea level to 100 m above sea level. It contains one vegetation type, which is the sand dune vegetation type.

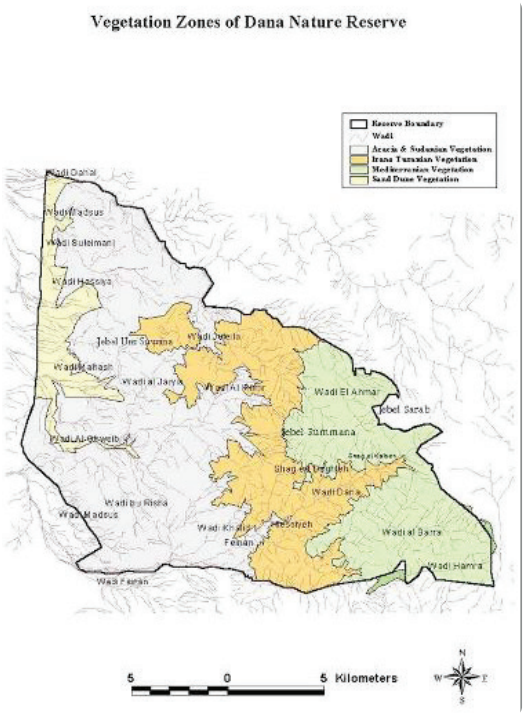

Figure 2.
Biogeographical zonation map of Dana Biosphere Reserve.
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2.5 Flora

The reserve contains more than 833 species of plants, representing one third of the plant species in Jordan of which 93 species are considered rare, and three species are considered new to science, which are *Silene danaensis*, *Micromeria danaensis* and *Rubia danaensis*.

2.6 Fauna

More than 258 species of invertebrates have been recorded in Dana BR. There are two species of amphibians in the reserve, and 42 species of reptiles, of which one is a globally endangered species. There are 215 species of birds in the reserve, of which four are globally endangered. There are 38 species of mammals recorded in the reserve.

3. Socioeconomic characteristics of the study site

3.1 Social structure of the population

Dana Biosphere Reserve covers about 300 km² within Tafilah governorate. The population of the villages in the populated areas around the reserve is about 33,400, of which 24,900 are from Tafilah, Aqaba and Karak governorates. Dispersed in villages and small towns, they have direct contact with the reserve and are considered as target groups. As can be see in Table 1, the eastern highlands of the reserve, from an administrative perspective, is part of the Tafilah governorate with 21,200 inhabitants, while the lower western area is part of Aqaba (Feynan, Rashaydeh, Qraiqrah) and Karak (Guaibeh) governorates with 3,700 inhabitants.

During the last fifty years these villages, especially those on the eastern and northern parts of the reserve, have witnessed substantial development, which has contributed to their significant lifestyle change. The local people, who were once nomadic and practiced traditional farming and grazing, have become more settled, and the villagers now live in cement houses with electricity and water. They also have easier access to infrastructure such as schools and health services.

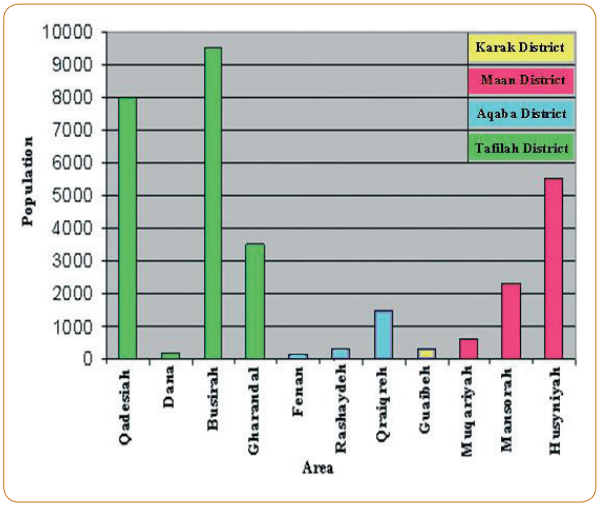
The local people living around the reserve originate from different clans and tribes. People in the upper eastern and northern areas work as farmers and livestock herders, and depend mainly on government jobs, as well as cement and phosphate factories situated outside the BR. Meanwhile bedouins on the lower western areas still depend on livestock grazing and farming activities, in addition to some employment at Feynan ecolodge in the Dana BR.

Below is a summary of the composition of village tribes surrounding the reserve:

Saudeen clans (Busirah and Garandal towns). Six clans live in both the Busirah and Garandal areas. They are: Al-Rofou and Al-Zaidaneen, the biggest clans; Mazaydeh, Musaideen and Eyal-salman, originating from Saudi Arabia; and Al-faqeer tribes, originating from Palestine.

Atata Tribes (Dana and Qadesiah area). Three tribes live in the Dana and Qadesiah area. They are Khawaldeh, Nanneh and Khsubah.

TABLE 1.
POPULATION DISTRIBUTION AROUND THE DANA BIOSPHERE RESERVE



Bedouin Tribes (Wadi Araba area). The lower western area around the reserve is inhabited by the Sadeen, Amarin and Rashaydeh tribes. It is also inhabited by the Azazmeh tribe that originated from Palestine, later migrating to Jordan following the 1948 crisis. Some of these families still roam the area looking for grazing sites and typically live in tents. Grazing is the major source of income for this tribe although some have begun to work as farmers, as well as seeking other locally available employment opportunities.

3.2 Uses of the biosphere reserve area and its surroundings

The studies conducted in the protected area indicate that throughout history this area was used by the population for mining, wood-cutting and grazing. There are two groups of people who use the reserve and its surrounding area as a source of food for their livestock, as outlined below.

The villagers in settlements around the reserve

These people make up the majority. Dana Biosphere Reserve is surrounded by several villages where most people work as farmers or livestock herders with some spending months inside the reserve for seasonal grazing with their livestock (Table 2).

TABLE 2:
NUMBER OF CATTLE IN THE AREAS AROUND THE RESERVE, ACCORDING TO INFORMATION OBTAINED IN 2007

Areas according to tribes	Livestock	
	Sheep	Goats
Busirah and Garandal (Saudeens)	3,225	823
Dana and Qadesiah (Atata)	3,166	796
Wadi Araba (bedouins)	345	5,852

Bedouins living in and around the reserve (in tents and caves)

Most are from the Azazmeh tribe, originally bedouin from the Negev area in Palestine, as well as some families from the Sadeen, Amarin, and Rashaydeh tribes. These bedouins live in tents in and around the reserve and use the reserve as a grazing area for their livestock. They try to set up their tents in the reserve or keep their livestock in caves, especially during the winter.

4. Improved dryland agriculture and rehabilitation of degraded areas

4.1 The Dana Biosphere Reserve approach

The reserve was established by the Royal Society for the Conservation of Nature (RSCN) for the purpose of conserving natural resources in general and natural biodiversity in particular. Nature conservation has been undertaken in Dana BR on the basis of scientific information gathered in the reserve, and covers all areas of the reserve's management plan: biodiversity, flora, fauna, and socioeconomic studies of the local community both inside and around the reserve. Using research methods, these studies have taken into consideration the experience and expertise of the local people on the research subjects under investigation.

Nature conservation has been undertaken in Dana BR using three main methods:

1. Raising awareness among the users of the natural resources, local stakeholders and government stakeholders through an outreach work plan, which was implemented in the reserve for all the target groups within the local communities. The awareness-raising programmes focused on the following areas:

- The sequence of unsustainable use of natural resources.
- Changing natural resource values by providing alternatives to unsustainable uses of natural resources.
- The promotion of local actions for local, regional and global environmental solutions.

The many sectors targeted by awareness raising programmes include:

- The heads of local clans and tribes.
- Local government stakeholders.
- Local farmers and livestock owners.
- Local school children.
- Women's groups in local communities.
- The local community in general.

2. Providing alternative resources to promote sustainable uses. The reserve established real life alternatives to unsustainable uses of natural resources, which are described below.

Preventing local people from maintaining some of the unsustainable uses of natural resources has, in some cases, greatly affected both their livelihoods and the local economy, thereby warranting a package of sustainable projects and alternatives that have since been introduced to Dana BR. These include ecotourism projects and socioeconomic production workshops. The reserve introduced ecotourism to the site in 1995, which was achieved through the establishment of three ecotourism sites within the reserve, considered the main tourism facilities. They

are Rumanah camp, Dana guesthouse and Feynan eco-lodge. Ecotourism has made a good contribution to the local economy with financial statistics revealing that each of the three sites brings in more than US$ 40,000 for each of the three main communities around the reserve. In addition, ecotourism, through its social responsibility programmes, has introduced other cultures and people to the local community, thus helping to enrich their local knowledge and experience.

Other projects managed solely by the reserve include socioeconomic production workshops that add value to the natural resources on site, which include the fruit drying workshop, the silver jewellery workshop, the goat leather-tanning workshop, and the olive oil soap production workshop (SUMAMAD Phase I). Buying organic crops from the orchard gardens of Dana village and other villages around the site for the fruit-drying workshop contributed to the development of the local economy. In addition, the silver jewellery workshop uses polished stones produced by the local women's cooperative to make jewellery. Dana BR is supporting the initiative by buying 80 per cent of their products. The leather-tanning project also buys goat hides from the bedouin communities as they have the highest number of livestock in and around the reserve. A workshop was established during SUMAMAD Phase I in which olive oil soap was produced in Dana orchard and is now sold in Dana and other RSCN reserves nature shops.

4.2 SUMAMAD Phase II approach

The sustainable integrity of Dana Biosphere Reserve requires proper management within the reserve and its surrounding areas. Prior to its establishment in 1989, livestock owners used to graze their flocks inside the reserve. The banning of grazing within the reserve resulted in the confinement of grazing activities in the surrounding areas, among them Al-Barrah. A number of the pastoral communities surrounding the reserve were employed by the RSCN as guards and officers, who are currently engaged in all ecotourism activities in the Dana Biosphere Reserve.

Al Barrah (Fig. 3) covers an area of around 40 km² characterized by rough topography. The vegetation structure is composed of two layers: woody plants (Phoenician juniper, evergreen oak, acacia, cypress) and herbaceous plants (*Artemisia sieberi*, *Anthemis melampodina, Achillea sp., Centaurea damascene, Echinops polyceras, Eryngium creticum, Filago desertorum,* and *Helianthemum cf. ledifolium*). Prolonged wintering of animals in Al Barrah depleted the herbs and damaged remnants of the woody vegetation, while continuous overgrazing and woodcutting are the major threats to the natural environment of Al Barrah.

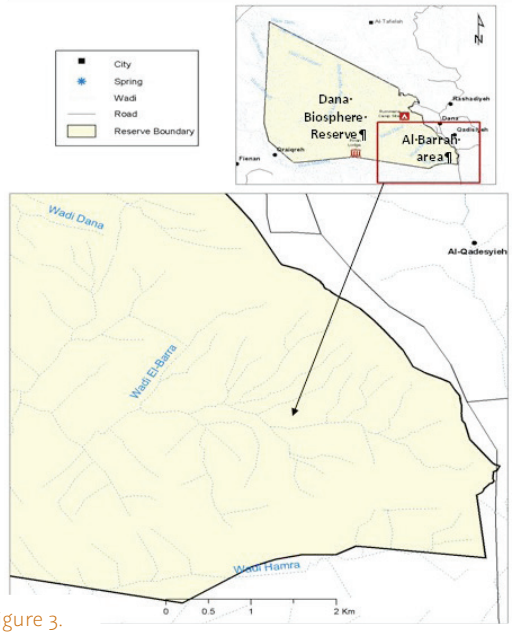


Figure 3.
Map of Dana Biosphere Reserve showing the targeted Al Barrah grazing area. © RSCN

In 2009, the RSCN collaborated with SUMAMAD to prepare a work plan (2009–2014) for the sustainable management of grazing resources of Al Barrah, which consists of four major components:

- Collection, compilation and analysis of available information.
- Baseline study of the targeted pastoral communities and the biophysical aspects of Al Barrah.
- Development of community-based grazing management.
- Development of a monitoring programme.

4.2.1 Community-based grazing management of Al-Barrah grazing area

Methodology

The methodology consisted of a chain of processes that were based on a participatory approach to mobilize the entire community, not just the livestock owners, around the objectives of the project. Some of these processes include learning about the community, participatory diagnosis and planning, the organization of livestock owners, and the development and implementation of community-based grazing management (CBGM).

Participatory approach

A participatory approach was adopted for all stages of the project. It is a collaborative decision-making process in which participation must involve some degree of shared control, as opposed to listening and consultation. This chain of processes actively involves all stakeholders in the process, helping to ensure that the plan developed is usable and meets their needs.

The benefits of the participatory approach are numerous and include:

- Allowing all farmers to voice their views, opinions, issues and concerns, enabling them to partake in the policy decision-making process.
- Developing a sense of ownership of the process and the product.
- Promoting learning from each other's experiences.
- Providing greater transparency in the policy-making process and proper delineation of accountability among stakeholders.
- Defining policy and programme goals/objectives and reciprocal commitments among stakeholder groups, as well as ways of measuring and monitoring these goals and objectives.

Learning about community

The community members of Al Qadesiah village are interested in two main issues:

- The rehabilitation (renovation) of the old stone houses in Dana village.

- Alleviating the problems faced by sheep grazing and goat flocks in the Al Barrah area during winter and spring seasons.

Rehabilitation of old houses in Dana village

The majority of stone houses in Dana village had collapsed many years ago and the dwellers of the village moved to Al Qadesiah village. One of the objectives of the 'Development of Ecotourism in Southern Jordan' project funded by USAID is to establish a 'Model Village' to promote ecotourism. The houses of Dana village were thus selected for renovation in order to conserve their ancient construction style and preserve the heritage of Dana village. Some people seized this opportunity and bought houses belonging to the poor villagers in the hope of generating future benefits from the renovation project. Moreover, several cooperatives popped up, each one claiming that it was the sole entity representing the Dana community

and therefore eligible to receive the renovation funds. The different conflicts of interest created an uncomfortable atmosphere among community members.

Grazing problems in Al Barrah

The livestock owners have been complaining of the chronic problems they face during the six-month wintering period in Al Barrah. In summary, the livestock owners lack the necessary funds to accomplish the following activities:

- Maintenance of water wells in Al Barrah to reduce the watering cost of their animals.
- Maintenance of the dirt road connecting Al Qadesiah village to Al Barrah area.
- Continuous degradation of grazing resources in Al Barrah and the need for credit to purchase feedstuffs to nourish their animals during drought.

The RSCN serves as the executive umbrella for both the 'Renovation of Ruined Houses Activities' in Dana village and the 'Sustainable Management of Grazing Resources Project in Al Barrah Area', creating some confusion among the local community that thought it was one sole project. Those interested in generating quick profits from the renovation of the houses for ecotourism, mainly those who are not livestock owners, are against livestock owners who are solely interested in securing feed and water resources for their flocks. The local community is therefore divided with rumours claiming that the government and the RSCN are planning to evacuate livestock owners from the traditional grazing domain in Al Barrah area.

Mobilizing community around the objectives of the sustainable management project

The RSCN targeted three levels to mobilize the local community around the project objectives: government officials, dynamic individuals in the community and livestock owners. Several meetings were conducted with these targeted groups:

- To verify the issues raised by community members (pollution of plants by cement dust, inaccessibility of roads to Al Barrah area, the need to rehabilitate the watering points (wells) during the wintering period in Al Barrah, and so on).
- To identify entry points to access and mobilize the community properly and sustainably.

Several meetings were conducted by the RSCN with local governmental officials to explain the objectives and potential impact of the 'Sustainable Management of Grazing Resources in Al Barrah Area' project (Fig. 4). The RSCN was successful in winning support from the governor, the director of the local agriculture directorate, and the president of Al Qadesiah municipality. The RSCN met with key persons several times, who claimed they were representing the interests of the local community, discussing with them the project objectives, while listening to their points of view. It was clear that these key persons were members of NGOs in the area who were trying to impose their opinions on the entire community. Notably, none of the active NGOs in the area represented the livestock owners.

The RSCN emphasized the idea behind the project, which is 'if the ecosystems surrounding Dana Biosphere Reserve become non-functional due to irrational use, the entire reserve will be damaged through time'. In other words, in addition to the global significance of the Dana Biosphere Reserve, its establishment has created many jobs for the locals, but these jobs will be lost if the integrity of the reserve is damaged. On the one hand, local community is confronted with limited job opportunities in Dana Biosphere Reserve and in the nearby Southern

Cement Factory, and on the other hand there are almost no job opportunities in government institutions. This means that the effective and sustainable collaboration of the local community and RSCN is essential to enhance the condition of grazing resources in Al Barrah and thus improve the livelihood of livestock owners. The RSCN invited all the livestock owners who use the Al Barrah area for wintering animals to attend a meeting to discuss all the issues related to the grazing and watering of their flocks. The half-day meeting was fruitful, and many of the livestock owners became the biggest supporters of the project.

Figure 4.
RSCN meeting with government officials in the area, key persons in the local community and livestock owners. © RSCN

Participatory diagnosis

The RSCN conducted a comprehensive survey to characterize animal production practices inside and outside the Al Barrah area. A structured questionnaire was designed and all the livestock owners using Al Barrah to winter their animals were interviewed. The results of the livestock owners' characterization survey were reported in the First SUMAMAD Progress Report in 2009.

The results of the survey were discussed with the livestock owners in a meeting planned on November 2009 in Dana Biosphere Reserve, whose main findings were:

- The harsh climatic conditions in the area obliged livestock owners to practice seasonal mobility whereby the flocks winter for 6 months in the lowlands (Al Barrah), and reside for 6 months in the uplands (Al Qadesiah village).
- Animals are hand-fed for almost a year. The high costs associated with feeding reduces profitability and forces livestock owners to allow their flocks to graze everything and anywhere to reduce feeding costs.
- The animal population that used to winter in Al Barrah totalled around 3,000 heads, with the average flock size of 130 heads.
- The flocks were well nourished with a good level of nutrition almost year long, even when grazing in Al Barrah, resulting in good animal performance.
- During wintering in Al Barrah, and because of the warm conditions, the external parasites (ticks, mites, lice) are a real problem for the animals. The inaccessibility of the Al Barrah area during winter hampers the veterinary services reaching the wintered livestock in the area.

The viewpoints of the livestock owners on the constraints to animal production in the area were in line with the findings of the survey. These were grouped into two categories: inside Al Barrah and outside Al Barrah.

Constraints to animal production inside Al Barrah

- Degradation of grazing resources
- Limited grazing areas
- Sedimentation of water wells
- Rough dirt roads

- Lack of clean water for drinking
- Lack of shelter during snowfall
- Predation by wolves
- Lack of veterinary services

Constraints to animal production outside Al Barrah

- Pollution of vegetation by the dust coming from the nearby cement factory
- Blockage of roads connecting Dana and Al Qadesiah during snowfall
- Lack of shelter during the hot summer
- High prices of feedstuffs
- Lack of veterinary services

The RSCN and the livestock owners agreed to grant priority to constraints to animal production inside the Al Barrah area, which were prioritized as follows:

- Renovation of water wells before November 2010. The targeted wells are Beir Al Maphry, Ghadeer Om Srar, Ghadeer Ben Odeh, Ghadeer Abo Tagah, Ghadeer Al Malaheez, Ghdeer Manzelet Nassar, and Ghadeer Ali Ben Hassan.
- Recruiting an expert in water harvesting to select, design and implement small-scale earth dams (capacity 25,000 m^3).
- Establishment of a cooperative for the livestock owners of Al Barrah.

Selection of community facilitators

The several meetings that were conducted with the three levels of the local community helped RSCN identify the most active and wise individuals who can support and serve the objectives of the Al Barrah project. The RSCN arranged several home visits to meet these active individuals so as to discuss more

TABLE 3.
THE PROPOSED ACTIVITIES OF AL BARRAH CAP OVER THE FOUR YEARS

Proposed activity	Locations	Key dates	Estimated costs (US$)	Responsibility	
				Execution	Funding
Year 2010					
Establishment of cooperative for the livestock owners of Al Barrah	To be located in Al Qadesiah village	October 2010	1,000	Al Barrah community and RSCN	Shared between SUMAMAD and Al Barrah community
Renovation of water wells	Om Laila	Oct–Nov 2010	5,000	Al Barrah cooperative	Shared between SUMAMAD and Al Barrah community
Year 2011–2014					
Control of insects and parasites in the caves in Al Barrah area	Wintering camps in Om Laila and Al Maghayer	Jan, Feb and March 2011	1,000	Al Barrah cooperative and RSCN	Shared between SUMAMAD and Al Barrah community
Capacity-building of staff of Dana Biosphere Reserve on grazing management	Al Barrah area	Feb–March 2011	3,000	RSCN	SUMAMAD
Selection, design and construction of small scale earth dams	Om Laila	2011–2012	Depends on the results of the economic feasibility study	Al Barrah cooperative and RSCN	Shared between SUMAMAD and Al Barrah community
Implementation of rest rotational grazing	Al Qanees and Khraqah	2011–2014	4,000	Al Barrah cooperative and RSCN	Shared between SUMAMAD and Al Barrah community

detailed aspects of the project (social, institutional, biophysical and financial). The RSCN entrusted the director of Dana Biosphere Reserve to work closely with these individuals and to benefit from their role as facilitators or coordinators between community members and RSCN project staff.

Participatory planning

The main objective of participatory planning is to develop a Community Action Plan (CAP), whose main elements include the timeframe, responsibility and funding (Table 3). The community addressed a wide array of 'activities' to implement over the four years (2010–2014). Some of these activities are unrealistic (i.e. opening new roads from Al Qadesiah to Al Barrah, building barns in the village to shelter animals during winter, subsidy of barley grains), and were subsequently dropped from the long list.

Organization of stockowners of Al Barrah grazing area

The RSCN advised the livestock owners to organize themselves in order to allocate the necessary funds for alleviating some of the constraints they faced in Al Barrah area. The livestock owners met many times in the headquarters of Dana Biosphere Reserve and in Al Qadesiah village, nominating five persons to make the necessary arrangements to establish a cooperative on their behalf in Al Barrah. After three months of meetings with local officials and decision-makers in Amman, the selected representatives managed to obtain a licence to establish a cooperative for the livestock owners of Al Barrah.

4.2.2 Application of water-harvesting techniques in Al-Barrah area

With the help of a hydrology specialist, the Project Management Unit (PMU) and Barret Dana cooperative undertook a one-day visit to watering points in the Al-Barrah area, which are the main sources of water for grazing animals.

Five watering points were visited and assessed, and three were selected for renovation and cleaning for use in the following grazing season. The others were marked for future renovation should the cooperative secure sufficient funding for the work.

The watering points of Al-Malaheez and Ali ben Hassan are located on the same water stream as the Al-Malaheez watering point – the first to be cleaned and renovated. The first step is to clean the pond and remove all the sediment that has accumulated over the years. The main pond will be enlarged by building a small wall to the end of it with a height of approximately 2 m (2 m from one side and 1.80 cm from the other). Although the height has been agreed upon, the width depends on the stream's width. In order to maintain water quality and reduce sediment accumulation in the ponds, four small dikes (50 cm height, 60 m to 70 m apart) were built on the main stream before the main catchments, with the purpose of reducing the speed of the running water and allowing them to precipitate most of the sediment before reaching the main pond.

The Ali ben Hassan pond needed less renovation as it is located downstream of Al-Malaheez. Al-Malaheez functioned as a dike, reducing the speed of running water. It is also large enough to catch a considerable amount of water after cleaning, without the need to build any walls.

The last watering point selected for renovation is Abo Tagah. The accumulated sediments were removed, and the pond was enlarged by building a wall at its end. Four dikes were constructed on the main stream with the same specifications as for the Al-Malaheez watering point.

It is agreed that each watering point will have one or two small ponds located nearby for watering the animals. Al-Malaheez will have two small ponds (70 cm wide, 40 cm deep and 2–3m long), Ali ben

Hassan will have one small pond, and Abo Tagah will have two ponds built with the same specification as for the Al-Malaheez watering point.

4.2.3 Capacity-building of Dana Biosphere Reserve staff and Barret Dana cooperative

Three workshops were conducted in SUMAMAD Phase II. The first workshop was part of the training programme to build capacity among Dana biosphere reserve staff on grazing management planning, while the other two built capacity of the Barret Dana cooperative.

Capacity-building of Dana Biosphere Reserve on rangeland management planning

A training programme was developed by the rangeland specialist that aimed to build capacity for technicians and supervisors of the reserves (where rangeland resources are exploited) in the field of rangeland management planning.

The training programme covers the following specific areas:

- Strategies for collecting the data and information required to develop a rangeland management plan.
- Ways to use the available data and information to formulate the main features of the rangeland management plan.
- Implementation of the rangeland management plan in the reserves.
- Evaluation of the implemented rangeland plan in the reserves.

The first training workshop 'Principles of rangeland management for the nature reserves' was held in Ajloun Forest Reserve from 5–8 September 2011, and dealt with the first and second objectives of the training programme.

During the four-day workshop the following topics were discussed.

i) Principles of rangeland management
   - Degree of grazing
   - Grazing season
   - Type of grazing animal
   - Distribution of grazing animals

ii) Information required for the rangeland management plan and how to provide it. The following data and information are required to calculate carrying capacity and to develop a draft rangeland management plan.
   - Field surveys of the physical and biological characteristics of rangeland resources in the reserve.
   - Field surveys of socioeconomic characteristics of the communities benefiting from the rangeland resources in the reserves.

iii) Methodology for calculating the carrying capacity of the pasture.

iv) Evaluation of rangeland systems appropriate to the targeted reserve.

v) Development of the draft rangeland management plan.

Capacity-building of Barret Dana cooperative

Two training workshops were conducted in SUMAMAD Phase II aimed at building the capacity of Barret Dana cooperative, and include:

A training programme for the women of livestock owners on the production of high quality dairy products.

The workshop aimed to:

- Give livestock owners assistance and solutions to solve some of the problems facing animal raising and dairy production.

- Enhance local community women skills in the manufacturing of high-quality dairy products for household and domestic marketing purposes.

Enhancing the quality of dairy products produced by local community women will increase household income and raise the standard of living of poorer families.

The two-day workshop was held in Dana Biosphere Reserve on 17–18 November 2012 and was divided into two phases. The following topics were discussed on the first half-day:

- A presentation of the animal production sector in Jordan, one of the most important agricultural sectors as a source of income, through small individual projects and large investment or cooperative societies.

- A presentation of farm management and modern techniques and methods of dealing with production in a scientific way, using laboratories and modern equipment in the manufacture of dairy products.

The rest of the workshop focused on:

- Practical training of milk processing methods and pasteurization, methods of milk separation, butter production steps, milk clot-making and the cheese industry, demonstrating the necessary equipment for the dairy industry for small scale livestock owners. Barret Dana cooperative contributed to the workshop by providing the necessary milk for the practical application.

The other workshop on the implementation of the rangeland management plan was carried out together with the development and adjustment workshop on the grazing management plan.

4.2.4 Implementation of the community-based grazing management in Al-Barrah area

The concept of community-based grazing management

It is a participatory approach where the local community or a sub-set of the community (i.e. owners of sheep and goats), government institutions (i.e. Ministry of Agriculture, Ministry of Environment), and non-governmental organizations (i.e. RSCN) collaborate to develop, implement and evaluate workplans to improve grazing and water resources, and to regulate grazing in a collective property (i.e. Al Barrah grazing area).

The driving force for community-based grazing management

Members of the local community, particularly the livestock owners, recognize the importance of Al Barrah area for wintering and grazing. They therefore showed strong willingness to collaborate with RSCN to protect and manage the very source of their livelihood. For RSCN, it is very important to properly manage Al Barrah area, which serves as a buffer zone for protecting the integrity of ecosystems inside the Dana Biosphere Reserve.

The goals of community-based grazing management

- Sustainable management of grazing resources.
- Equity among the livestock owners (equitable access) and improvement of livelihoods.
- Building strong partnership among livestock owners, the local community and RSCN.

The features of community-based grazing management

- Security of tenure that grants livestock owners comprehensive rights to use grazing and water resources for many years. These rights may be inherited and can later be passed onto the children of livestock owners.

- Eligibility to receive technical assistance from RSCN or other experienced entities to help achieve the sustainable management of grazing resources.

The components of community-based grazing management

- Organized community. The targeted community is living in Al Qadesiah village, while the focus group is the livestock owners of sheep and goats that winter their animals in Al Barrah. The number of households having livestock and benefiting from Al Barrah is around 30 who own 3,200 heads of sheep and goats. The project succeeded in organizing the livestock owners under the umbrella of the Barret Dana Cooperative for Livestock Production (BDCLP). The members of the cooperative elected an administrative committee to follow up on day-to-day activities.

- Availability of technical assistance. The RSCN provided the needed researchers and expertise (i.e. on grazing management, water harvesting, socioeconomics, public awareness, and so on) to strengthen the BDCLP. The researchers collected, analysed and reported the results of the baseline studies (surveys) pertaining to the biophysical and socioeconomic aspects of the pastoralists and their grazing ecosystem. The findings of the different surveys on vegetation, water resources, soils, the pastoral community and the livestock determined the approach and interventions needed to achieve the objectives of rational grazing management. Moreover, the technical team will collaborate with BDCLP members to develop and implement a practical monitoring programme to assess the efficacy of the grazing management concept.

- Availability of funds. The targeted community is poor and depends primarily on livestock husbandry for income. With the help of RSCN, the newly established cooperative developed an ambitious workplan that requires generous funding for its implementation in the coming years, calling for fundraising from local and external sources.

Processes of developing community-based grazing management

- Database and collection of information. Several field surveys were conducted on the biophysical aspects of Barret Dana and the users of the area. Information was gathered on the structure and function of vegetation, the socioeconomic aspects of livestock owners, water and feed sources, grazing practices, and the impact of grazing and wintering on vegetation. The outcomes of the collected data include: estimates of total grazing capacity, estimates of household grazing share, knowledge of the spatial and temporal mobility of flocks inside Al Barrah area, and identification of the threats and opportunities to enhance productivity and the diversity of grazing resources in Al Barrah area.

- Consultation with local community. The expertise and technical team of RSCN conducted several meetings with the local community, livestock owners and officers of government institutions in the area to discuss pressing issues related to wintering and grazing in Barret Dana. The community demands were listed and several workshops and meetings were arranged to refine the long list of demands.

- Organization of stockowners. The RSCN succeeded in organizing the livestock owners, and the Barret Dana Cooperative for Livestock Production (BDCLP) was established to achieve the objectives of community-based grazing management. The RSCN believes that BDCLP

is the right channel to communicate with the local community, serving as the strong arm to regulate grazing in the area. The BDCLP elected an administrative committee or council to follow-up on day-to-day activities.

- Capacity building. The RSCN collaborated with experts and members of BDCLP to design and implement several training programmes to enhance community awareness on the participatory management of grazing resources and the basics of developing grazing plans and keeping livestock records.

4.2.5. Grazing plan

The components of a grazing plan include: annual grazing capacity, the spatial mobility of flocks, and the number of grazing days.

Annual grazing capacity

The findings of the vegetation survey conducted at Al Barrah in 2010 indicate the following:

- Estimate of potential grazing area in Al Barrah was 19.2 km^2.
- The overall annual grazing capacity of Al Barrah was 3.9 SUM ha^{-1} for 90 days of grazing.
- The contribution of the four grazing locations to overall annual grazing capacity of Al Barrah was 74.1% for Khraqah, 14.1% for Al Qanees, 2.2% for Om Laila, and 9.6% for Om Al Fottos.
- The total number of sheep and goats that can be accommodated at Al Barrah is around 3,118 heads.
- The household grazing share is around 125 heads.

Number of grazing days

- The reasonable grazing period was 90 days (1 January to 30 March or from the 1 December to the end of February).
- The designated number of grazing days may vary, according to cold conditions in the upland or vegetation conditions in Al Barrah.

3 Responsibilities of stakeholders

The main stakeholders influencing the functioning of community-based grazing management in Al Barrah include: RSCN, BDCLP, government institutions such as the Ministry of Agriculture (MoA), Ministry of Environment (MEn), the local or regional governing council (GC), and donors.

TABLE 5.
MAIN ACTIVITIES OF COMMUNITY-BASED GRAZING MANAGEMENT AND RESPONSIBILITIES OF STAKEHOLDERS

Activities/Measures	RSCN	BDCLP	MoA	MEn	GC	Donors
Deciding on the start of wintering	√	√				
Development of grazing plan	√	√				
Deciding on the spatial and temporal mobility of flocks		√				
Regulation of grazing		√			√	
Record-keeping		√				
Financial management		√				
Technical assistance	√		√	√		
Monitoring of grazing resources	√	√				
Deciding on range improvements	√	√				
Capacity-building	√		√	√		√
Conflict resolution	√	√	√	√	√	
Funding	√	√	√	√	√	√

5. Scenarios for future land use changes

5.1 Regulation of grazing in Al Barrah

The information collected and the database revealed that wintering sheep and goats in Al Barrah area, which extends from 30 October to 30 March every year, had damaging effects on the vegetation in the area because of early grazing and the overgrazing of plants during grazing months. The experts from RSCN conducted several consultations with the livestock owners to discuss managing the grazing inside Al Barrah and to agree on grazing strategies. The three grazing scenarios that stemmed from these consultations include:

- ***Scenario 1:*** No change in the spatial and temporal mobility of flocks in Al Barrah area; wintering of animals will continue as usual. This scenario was totally rejected by the experts of RSCN because of its drastic effects on the integrity of the Al Barrah ecosystem.

- ***Scenario 2:*** Animal grazing will be terminated before the 30 March (at the end of February) to give the severely defoliated plants an opportunity for new regrowth before the desiccation of the soils in the area. The livestock owners had many concerns with this scenario because the decision to leave Al Barrah and return to Al Qadesiah village would depend on the weather conditions prevailing in the uplands; there is a risk that the animals will be vulnerable to cold conditions.

- ***Scenario 3:*** Applying rest rotational grazing, alternating between the two main grazing locations in Al Barrah/Al Qanees and Khraqah. Initially, the livestock owners refused the idea of rest rotational grazing because each livestock owner habitually grazed in a certain location every year and was unwilling to change. The gathering of flocks in one location is the touchstone for creating conflict among livestock owners, which may extend to the pastoral community. In-depth discussion of this scenario enabled the RSCN experts to convince the livestock owners to adopt it with minor modifications. Changes include allowing flocks to graze during winter at the two locations as usual, but the flocks grazing in Al Qanees will be removed before 30 March for grazing in Khraqah. The following year, the flocks grazing at Khraqah will be removed before 30 March for grazing in Al Qanees.

5.1.1. Spatial mobility of flocks

Scenario 3 describes the planned spatial mobility of sheep and goat flocks inside the Al Barrah. Khraqah and Al Qanees grazing locations that will absorb the bulk of the grazing pressure. It is understood that the wintering of animals in Al Barrah starts on the 1 November every year to escape the cold conditions prevailing in Al Qadesiah village where the majority of flocks are raised. Grazing usually starts directly after the animals are moved to Al Barrah. During the period from November to December, the amount of grazing material is very low and the animals are fed barley grains, straw and wheat bran. This means that the scant quantity of grazing material restricts the mobility of wintered animals during the first 60 days of residency in Al Barrah.

After rainfall, usually in January and February, new plant growth encourages the livestock owners to move their animals to all possible places inside Al Barrah. The central point of scenario 3 is moving animals from Khraqah or Al Qanees 2–3 weeks earlier than usual to give the defoliated plants enough time to recover. In the first year, the flocks grazing

at Khraqah will be moved in late February or early March to Al Qanees or to Om Al Fottos, depending on the condition of the vegetation. In the second year, the flocks roaming Al Qanees will be moved to Khragah and Om Al Fottos in late February or early March. This mobility is expected to reduce the number of grazing days every year at each location during the growing season, thereby reducing the grazing pressure on the palatable plant species.

TABLE 4.
SCENARIO 3: SPATIAL AND TEMPORAL MOBILITY OF SHEEP AND GOAT FLOCKS AMONG THE GRAZING LOCATIONS IN AL BARRAH W=WAIT (NO GRAZING), G=GRAZING.

Year	Date	Khraqah		Al Qanees		Om Al Fottos		On Laila	
		W	G	W	G	W	G	W	G
1	Nov–Dec	*		*		*		*	
	Jan Feb		*		*		*		*
	March	*			*	*			*
2	Nov–Dec	*		*		*		*	
	Jan–Feb		*		*		*		*
	March		*	*			*	*	

5.2 Establishment of a grazing regulating committee (GRC)

The GRC is the mechanism for implementing scenario 3. Members of GRC comprise three representatives from DBCLP, two observers among livestock owners, one representative from the local government council, one representative of the Ministry of Agriculture, the Director of Dana Biosphere Reserve and two experts, making a total of ten members, of which eight are acting members plus two observers. Members of the GCR elect or select a chairman and a clerk.

The responsibilities of GRC include:

- Articulating the goals and guidelines (management approaches, methods, and practices), and regulating the grazing inside Al Barrah.
- Determining the household grazing share based on the total carrying capacity of Al Barrah.
- Administering the regulations for the management and use of the grazing locations.
- Carrying out improvements to the grazing locations (development of water points, plantation of fodder shrubs, and so on).

The main responsibilities of the clerk include:

- Arranging and keeping records of meetings.
- Dealing with all correspondence.
- Keeping and updating records of animals owned by the livestock owners.
- Managing all cash transactions and keeping accounts.
- Arranging annual audits of the accounts.

6. Ensuring sustainable livelihoods through alternative income-generating activities

The RSCN and the Barret Dana cooperative prepared a small proposal and submitted it to the Global Environment Facility (GEF), which was approved, securing the funds. During 2012, the Barret Dana cooperative began to implement their first project by using the funds to build their offices, a small veterinary clinic and a fodder mill, and also to plant a small pilot area with Atriplex (20 dunums[1]) inside the reserve and Alfalfa (30 dunums) outside the reserves for the production of green fodder.

1 A dunum is a measurement of land commonly used in Jordan, which is equal to 1,000 m² or 0.10 ha.

7. Results obtained

7.1 Characterization of livestock owners grazing in the Al-Barrah study

7.1.1 Tribes

The people of the Atata tribe are the native inhabitants of Dana Biosphere Reserve. Their history in Dana dates back 400 years, but their original settlement in the area dates back to more than 6,000 years. Besides the presence of the Atata people, archeological discoveries suggest Paleolithic, Egyptian, Nabataean and Roman settlements in Dana. It is worth noting that after the collapse of the historical Dana village, the majority of inhabitants migrated to Al Qadesiah village. The promotion of ecotourism in Dana Biosphere Reserve helped revive Dana village. The main sub-tribes include Al Khsubah, Al Khawaldeh and Al Nanneh. The majority (71.4% of the livestock owners were from Al Nanneh compared to 25% for Al Khsubah and 3.6% for Al Khawaldeh.

7.1.2 Size and composition of families

The family size average 10.8 members, which is higher than the national average of 7.1. In reality, the larger family consisted of smaller families with all the family members living under one roof as a result of poverty. The family members were grouped into three age categories: less than 5 years (C1), between 5 and 10 years (C2), and more than 10 years (C3). The majority of males and females of C3 showed the highest number and averaged 6.1 and 4.7 per household, respectively (Fig. 5).

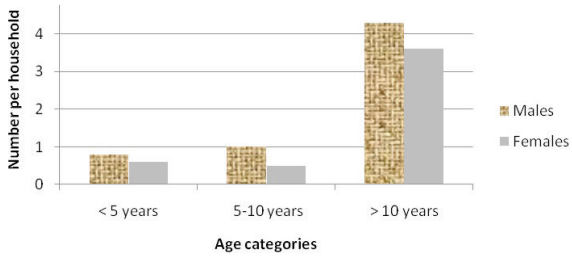


Figure 5.
Number of males and females per livestock owner. © RSCN

7.1.3 Sources of income

The vast majority of income derives from animal production (sale of live animals and animal products) (Fig. 6). Agricultural activities (82.1%) include olive orchards, vegetables, and the cultivation of barley and wheat. Job opportunities (39.3%) was limited in the area and confined to labouring in the Al Rashadeyah cement factory, working as employees in Dana Biosphere Reserve, as well as a limited number of positions in government institutions in Al Qadesiah. Other sources of income include the National Assistance Fund. More information on the income and spending are needed to determine the effect of future interventions on the socioeconomic status of livestock owners.

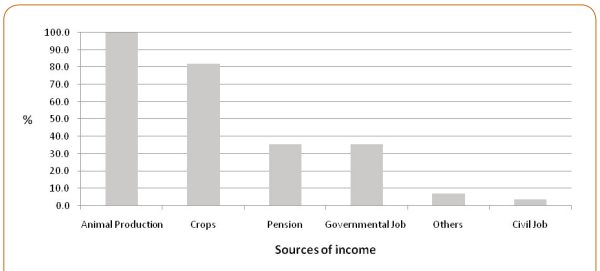


Figure 6:
Income sources of the livestock owners interviewed in Al Barrah, Dana Nature Reserve. © RSCN

7.1.4 Housing

The livestock owners of Al Qadesiah live in brick houses (82.1%) with water and electricity, or tents (17.9%) (Table 6). During the wintering period (November to March) in Al Barrah, the majority of livestock owners live in tents (62.5%) and a few in caves (37.5%). The livestock owners use the same wintering camps (the location of the caves or the tents) every year. The main reason for moving the sheep and goat flocks to Al Barrah is the lack of suitable barns in Al Qadesiah to protect the animals from the chilling winds and snow during winter. The poorest farmers cannot afford to pay the construction costs of the barns they need for their livestock.

TABLE 6.
TYPE OF DWELLING OF THE LIVESTOCK OWNERS IN AL QADESIAH AND AL BARRAH

House type	Al Qadesiah		Al Barrah	
	No.	%	No.	%
Brick	23	82.1	-	-
Tent	5	17.9	10	62.5
Cave	-	-	6	37.5

7.1.5 Animal population

The number of sheep and goats exploiting the resources of Al Barrah total 2,748 heads (451 goat and 2,297 sheep). The low goat–sheep ratio could be attributed to the fact that the sheep are more tolerant than goats to the cold conditions prevailing in the Al Qadesiah area. The sheep (*Ovies aries*) belong to the Awassi breed, which is characterized by a broad fat tail and coarse wool fibres and is native to Jordan, Syria, Palestine, Iraq and Turkey. The goats (*Capra haircus*) belong to either the Damascus breed (a dairy type) or to the black goat breed that is native to Jordan.

The majority (67.9%) of the flocks were mixed with sheep and goats. Out of the 28 flocks, there were two sheep flocks and seven goat flocks. The male–female ratio was 0.06 for sheep and 0.05 for goat compared to the usual ratio of 0.10 (one male for 10 females). It seems that the livestock owners deliberately reduced the number of males in the flock in an attempt to reduce the feeding costs.

7.1.6 Grazing season

The administrative staff of the Dana Biosphere Reserve and the guards of the Ministry of Agriculture are the two authorities responsible for the regulation of grazing in Al Barrah. The livestock owners are permitted to stay in Al Barrah from November to March. Wintering in Al Barrah may start before November in case of cold conditions or end before March in hot conditions.

The livestock owners claimed that the main reason for staying at Al Barrah was to escape from the cold conditions prevailing in winter in Al Qadesiah village (1,500 m asl). The feedstuffs for wintering (barley grains, wheat bran and grain's straw are transported from the village to the wintering camps in Al Barrah by trucks and pickups at a cost of JD 10-12 per ton (~US$15). The feedstuffs are either stored in the caves or in trucks covered with plastic sheets. They are usually stored for short periods of time (2 to 3 weeks) and replenished continuously. Animals graze at Al Barrah during the critical growth period of herbaceous plants, when destructive early grazing is common. The herbaceous component is completely degraded and signs of heavy grazing were obvious on the oak trees. Woodcutting by the livestock owners was practiced during the wintering period for cooking and heating purposes.

7.1.7 Grazing locations

Although the grazers had established permanent wintering camps, their flocks graze in all parts of Al Barrah without restriction. Knowledge on the preferred grazing locations helps to select the right locations for interventions aimed to enhance the condition of grazing sources. The preferred grazing locations inside and outside Al Barrah are shown in Table 7.

TABLE 7.
PREFERRED GRAZING LOCATIONS INSIDE AND OUTSIDE AL BARRAH AREA, DANA BIOSPHERE RESERVE

Preferred grazing locations	
Inside Al Barrah (March–November)	**Outside Al Barrah (April–October)**
Inside Al Barrah (March–November)	Outside Al Barrah (April–October)
Alledoar	Wadi Salam
The Caves	Aljmaeah
Alnazaz	Alfreajah
Western Fokharah	Alghor
Almalaheez	Alhala
Fawaz	Albaqaah
AlQanees	Wadi Hakama
Eastern Fokharah	Telaa Albotom
	Um Hmaitah
	Shjaret altayarah
	Alfjaij
	Deraa bn Saleh
	Dana
	Alsoqaah
	Haydarah
	Alsheehah
	Alhaqreah
	Ain Altareeq
	Eastern Alqadessyah

The livestock owners indicated that several problems were encountered inside and outside Al Barrah grazing area (Table 8). The majority of them claimed that the present grazing acreages are not enough to accommodate the existing number of sheep and goats.

TABLE 8.
PERCENTAGE OF LIVESTOCK OWNERS' PERCEPTION ON THE PROBLEMS DURING GRAZING INSIDE AND OUTSIDE AL BARRAH

	Inside Al Barrah (percentage)	Outside Al Barrah (percentage)
Limited grazing areas	89.3	100
Lack of water resources	50.0	57.1
Rough roads	28.6	-
Predation by wolves	3.6	3.6
Conflict with reserve guards	7.1	-
Pollution of plants by cement dust	-	32.1

7.1.8 Feed sources

The irrational grazing for prolonged periods outside the Al Barrah area has almost depleted the entire native vegetation. In addition, the relatively long wintering period (5 months) of animals inside Al Barrah area, which coincides with the onset of growth of the herbaceous plants, encouraged 'early grazing' with drastic effects on soils and vegetation. In other words, the condition of native vegetation inside and outside Al Barrah is poor, necessitating the proper regulation of grazing.

Continuous deterioration of vegetation inside and outside Al Barrah resulted in a greater dependency on traditional feedstuffs (barley grains, wheat bran and tibin[2]) (Table 9). All the livestock owners nourished their animals on traditional feedstuffs throughout the year, even during the grazing season. The offered amounts of traditional feeds varied according to grazing conditions and the animal production stage.

2 Shredded straw of barley.

The average daily cost of feeding was around JD 0.22 per head (~ 30 US cents) during the wintering period in Al Barrah, excluding the cost of feeding on herbaceous plant remnants and the leaves of oak trees.

TABLE 9.
AMOUNT AND COST OF TRADITIONAL FEEDSTUFFS DURING WINTERING INSIDE AL BARRAH, DANA BIOSPHERE RESERVE

	Barley grains	Wheat bran	Tibin
Total amount (ton)	263	65	6
Average daily intake (kg per head)	0.64	0.69	0.26
Price per ton	150	115	100-250*
Average cost (JD per head)	0.10	0.08	0.04

* JD2 per bag weighing 20 kg for local tibin, and JD10 per bag weighing 40 kg for imported tibin from Lebanon.

The problems pertaining to the traditional feed resources, as provided by the livestock owners, are summarized in Table 10. They all agreed that there were no problems in availability, except for tibin, nor the quality of the traditional feedstuffs.

TABLE 10.
RESPONSES (PERCENTAGE) OF THE INTERVIEWED LIVESTOCK OWNERS ON THE PROBLEMS PERTAINING TO TRADITIONAL FEEDSTUFFS

	Barley grains	Wheat bran	Tibin
Availability: No problems	100	100	20
Quality: No problems	100	100	100
Storage: No problems	100	100	100
Prices: High Moderate	100 -	100 -	100 -
Transportation cost: High Moderate	100 -	100 -	100 -

The livestock owners claimed that the prices and transportation costs of the feedstuffs were high. In this regard, it is worth noting that the government of Jordan adopted a phasing programme in 1996 to remove the subsidy on animal feed. In the last three years, the prices of traditional feedstuffs are based on the international market for feed.

7.1.9 Water sources

Al Barrah grazing area is poor in water resources. All livestock owners purchase water from external sources for their animals during wintering in Al Barrah (Table 11). A small proportion (7.1%) of livestock owners use the springs in Al Barrah for watering their animals. Large water tanks with a capacity of 3-6 m^3 (75%), plastic barrels in small pick-ups (10.7%), and plastic jars mounted on donkeys (3.6%) were means used to haul water to Al Barrah. Hauling water is tedious work, which is exacerbated by the difficult topography inside Al Barrah.

TABLE 11.
ANIMAL WATERING SOURCES INSIDE AND OUTSIDE AL BARRAH, DANA BIOSPHERE RESERVE

Water Sources	Inside Al Barrah	Outside Al Barrah
Springs	3.4	-
Hauling water	96.6	78.6
House water pipes	-	21.4

In compliance with the grazing regulation, all sheep and goat flocks move from Al Barrah to Al Qadesiah village in March. The tap water supplied to the houses and the purchase of water tanks were the watering sources for animals during the spring and summer seasons, though the livestock owners complained about the high prices of water. Estimates of water costs during wintering inside and outside Al Barrah are presented in Table 12. The amount of water consumed during the wintering period is 3,320 m^3 with an estimated cost of JD 16,920 (~ US$24,000). The cost of

watering the animals could be considerably reduced by renovating the natural springs and several of the small earth dams (100–200 m³) constructed across the wadis inside Al Barrah.

TABLE 12.
AMOUNT AND COST OF WATERING ANIMALS INSIDE AND OUTSIDE AL BARRAH, DANA BIOSPHERE RESERVE

	Inside Al Barrah	Outside Al Barrah
Watering period (month)	5	7
Amount of water (m³)	3320	4648
Average price (JD per m³)	5.4	5.4
Average cost (JD per head per day)	0.05	NA*

* NA: not available

7.2 Vegetation Baseline Study of Al Barrah

7.2.1 Study area

The area of Al Barrah is around 64 km² and is characterized by rugged topography. The vegetation structure is composed of two layers: woody (Phoenician Juniper, evergreen oak, acacia, cypress) and herbaceous (*Artemisia sieberi*, *Anthemis melampodina, Achillea sp., Centaurea damascena, Echinops polyceras, Eryngium creticum, Filago desertorum, Helianthemum cf. ledifolium,* and so on). Prolonged wintering of animals in Al Barrah depleted the herbs and damaged the remnants of the woody vegetation. Continuous overgrazing and woodcutting are the major threats to the natural environment of Al Barrah.

7.2.2 Sampling locations

The survey conducted on livestock owners in April 2009 revealed that the pastoralists preferred four grazing locations in Al Barrah area: Al Qanees, Khraqah, Wadi Om Laila and Om Al Fottos (Fig. 7).

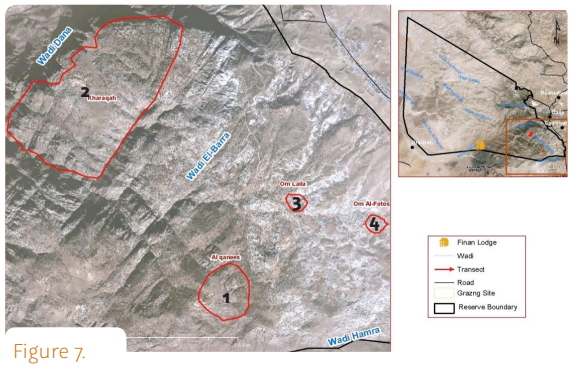


Figure 7.
Targeted grazing locations: 1.Al Qanees, 2. Khraqah, 3. Wadi Om Laila and 4. Om Al Fottos in Al Barrah area. © RSCN

The total area of Al Barrah is 64 km². Field visits revealed that around 70 per cent of the Al Barrah area is inaccessible to grazing animals because of the rugged topography (i.e. rocky outcrops, steep cliffs). The estimate of the potential grazing area in Al Barrah is around 19.2 km². The proportion of Al Qanees, Khraqah, Wadi Om Laila and Om Al Fottos of the potential grazing area is 25%, 60%, 10% and 5%, or 1,152, 480, 96, and 192 ha, respectively. The livestock owners viewed Wadi Om Laila merely as a wintering refuge and its contribution to Al Barrah forage production is negligible.

7.2.3 Al Qanees grazing location

Biomass production

Mean fresh and dry weights of vegetation was 137.1 ± 129.7 and 25.0 ± 23.6 g m^{-2}, respectively. Percentage dry matter averaged 18.2. Dry matter production of forage plant species was estimated to be around 60% of vegetation biomass, or 150 kg DM per ha.

Annual grazing capacity and household grazing share

Grazing capacity is defined as the maximum possible rate of animal stocking without causing damage to vegetation, water or related resources. Routine management determines grazing capacity for a certain grazing allotment over several years. The information collected is used to develop general guidelines for grazing capacity, taking into consideration the variability of climatic conditions and vegetation types.

Forage production at Al Qanees location totaled 72,000 kg dry matter (DM). The computed grazing capacity was 444 sheep units (SU) for a period of 90 grazing days or a stocking rate of 2.78 sheep units monthly ha^{-1}. The findings of the livestock owner survey revealed that the number of households traditionally using the natural resources of Al Barrah was 25. The grazing share was 18 sheep or goat heads per household.

7.2.4 Khraqah grazing location

Biomass production

Mean fresh and dry weights of vegetation at Khraqah were 225.0 ± 227.49 and 65.03 ± 65.74 g per m^2. The biomass of forage species amounted to around 50 per cent of vegetation biomass and averaged to 325 kg DM per ha.

Annual grazing capacity and household grazing share

Total dry matter production of forage species at Khraqah was 374,400 kg, which is enough to support 2,311 head for 90 days. The computed stocking rate was 6.02 SUM ha^{-1}. A household can graze up to 92 heads of sheep and/or goats at the Khraqah location for 90 days.

7.2.5 Om Laila grazing location

The presence of several water ponds and caves, and its proximity to paved roads to truck feedstuffs and water make Om Laila a preferred location for livestock owners to winter their flocks. The scattered piles of animal manure, demarcated stone yards, and waste found throughout the area are characteristic of Om Laila wintering area.

Biomass production

Means of fresh and dry weights of Om Laila vegetation were 218.2 ± 88.5 and 63.2 ± 24.6 g per m^2, respectively. Percentage dry matter averaged 29.4 ± 3.3. Forage plant species constituted around 40 per cent of vegetation biomass and yielded 252.8 kg DM of forage ha^{-1}.

Annual grazing capacity and household grazing share

Om Laila produced a total of 48,480 kg DM of forage that can nourish 299 livestock heads for 90 days with a computed stocking rate of 4.68 SUM ha^{-1}. The grazing share per household was around 12 heads of sheep and/or goats.

7.2.6 Overall grazing capacity of Al Barrah

The estimate of potential grazing area in Al Barrah was 19.2km^2. The four grazing locations: Khraqah, Al Qanees, Om Laila, and Om Al Fottos constituted 74.1%, 14.1%, 2.2% and 9.6% of total potential grazing capacity, respectively. The computed number of sheep units that can be grazed for 90 days in the Al Barrah area totaled 3,118 heads or a stocking rate of 3.90 SUM ha^{-1}. Grazing share averaged 125 sheep units per household. It is worth noting that the grazing capacity was computed for a good rainy year. Scenarios of grazing capacity for dry and normal years are required to promote flourishing of perennial plants in the area.

7.3 Development of monitoring programme for Al Barrah grazing area (Barrat Dana)

7.3.1 Monitoring approach

The monitoring approach will emphasize both the empirical data (scientific knowledge) and local knowledge in rangeland monitoring and management. The problems of the Al Barrah grazing area are complex, requiring an integration of knowledge from researchers and grazers, while opening dialogue on environmental sustainability with the beneficiaries from the area to develop a sound and practical monitoring programme.

7.3.2 Monitoring sites

Sites used for the baseline study in 2010 could serve as monitoring sites to evaluate the impact of the proposed grazing plan (stocking rate and timing of grazing) on the main attributes of key forage species. To compare attributes of grazed versus non-grazed vegetation, at least one enclosure (e.g. 50m x 100m) should be constructed at each targeted grazing location in Al Barrah.

7.3.3 Key forage species

The 3–5 most prolific (dominant) forage species experiencing the most use during the period of grazing on the monitoring site will be identified to develop a general picture about the structure of the vegetation. Selection of key forage species will be based on the knowledge of livestock owners grazing their flocks in Al Barrah and researchers' experience. The selection criteria will include high forage production, nutritive value of produced forage, palatability, length of greenness period, tolerance to grazing, tolerance to drought, and perenniality.

7.3.4 Monitoring schedule

Timetable: Monitoring will be initiated and continued for 5 years (2012–2016). Sampling of vegetation attributes will commence in the 1st or 2nd week of April directly after termination of grazing in the area.

Sampling protocol: For each targeted grazing area, four transects (T1, T2, T3 and T4), 100 m each with 5 m inter-spacing, will be delineated inside the fenced area (50m x 100m). Quadrats of 1m² or macro-plots (5m x 5m) will systematically be placed at 10m intervals along each transect. A total of 40 quadrats or 8 macro-plots will be sampled on each sampling date.

Two transects of 50m will be delineated at each of the four sides of the fenced area (TN1,2, TE1,2, TS1,2 and TW1,2) to serve as sampling units to compare vegetation attributes inside and outside the fenced area (Fig. 8). Similarly, the quadrats or macro-plots will be placed along the delineated transects outside the fenced area. Five quadrats or two macro-plots will be sampled along each transect; a total of 40 quadrats or 8 macro-plots will be sampled.

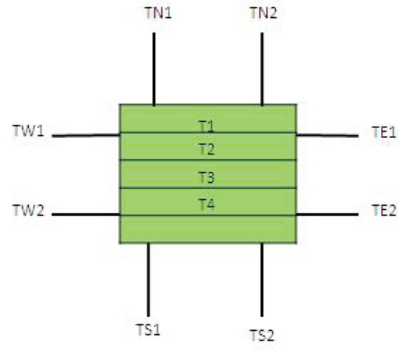


Figure 8.
Schematic representation of the intended layout of the permanent transects for monitoring purposes. © RSCN

7.3.5 Sampling techniques of vegetation attributes

Ground cover: The ground cover (vegetation, rock-outcrops, stones, litter) will be estimated visually for each quadrat (Bonham, 1989). The presence of animal pellets, signs of grazing on plants, and flowering of plants in the quadrats will also be recorded. Percentage ground cover and percentage bare soil will be computed with these formulae:

Ground cover % = Vegetation cover % + rock outcrop cover % + stones cover % + litter cover % + cryptogams cover % + dry stumps and clumps cover %

Bare soil % = 100% - ground cover %

Vegetation structure: Vegetation structure (physiognomy or architecture) refers to the number of strata and the spatial distribution of plant species. General vegetation structure will be determined visually for each grazing location.

Plant cover: Coverage of all plants encircled inside the quadrat will be visually estimated. Percentage cover of forage species and non-forage species will be visually estimated separately.

Plant frequency: A single plot technique will be used to record the presence of plant species. Plant frequency for each species will be expressed as the numbered quadrats where the species present are divided by the total number of sampled quadrats (Bonham, 1989). The frequency will be calculated with this formula:

$$\text{Frequency} = \frac{\text{Number of quadrates in which species occurs}}{\text{Total number of quadrats}} \times 100$$

Plant density: The number of plants for each individual species regardless of whether they are annual or perennial will be counted and recorded (Bonham, 1989). Plant density will be expressed as the number of plants per quadrat, whether they are a mature individual or seedling. The plant density will be calculated with this formula:

$$\text{Density} = \frac{\text{Number of plants recorded in quadrats}}{\text{Total number of quadrats}} \times 100$$

Plant diversity: The diversity of the identified plant species will be expressed in three ways: i) species richness (Magurran, 2004), ii) Shannon index (Krebs, 1998), and iii) Raunkiaer's life form (Raunkiaer, 1934).

i) Species richness will be estimated as the average number of plant species of all sampled quadrats in the entire key area and expressed as the number of plant species per quadrat. Actually, it represents the *alpha* (α) diversity of species. The species richness will be calculated with this formula:

$$\text{Species richness} = \frac{\text{Number of plant species recorded in quadrates}}{\text{Total number of quadrats}} \times 100$$

ii) Shannon diversity index (H') is commonly used to characterize species diversity in a community. It accounts for both abundance and evenness of the species present. The proportion of species *i* relative to the total number of species (*pi*) is calculated, and then multiplied by the natural logarithm of this proportion (ln*pi*). The resulting product is summed across species and multiplied by -1. The Shannon Index was calculated with this formula:

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

iii) The life forms of the identified plant species will be categorized according to Raunkiaer's classification, which is based on the location of the renewal bud in relation to soil surface and the nature of organs shed in the harsh season.

The categories include *parenophytes* (trees and shrubs taller than 1 m), *chamaephytes* (semi-shrubs), *hemicryptophytes* (perennial plants in which the renewal bud is located at the soil surface), *geophytes* (perennial plants in which the renewal bud is located below the soil surface), and *therophytes* (annual plants in which the renewal bud is in the seed).

Plant biomass: The harvesting technique will be used to determine the vegetation biomass, where all the plants (shrubby and herbaceous species) rooted in the quadrat will be harvested by hand shears to ground level (Kent and Coker, 1999; Cook and Stubbendieck, 1986). The harvested material will be weighed before and after drying in an oven at 75±5 °C for 48 h. The biomass values will be expressed as kg DM ha^{-1}.

7.3.6 Sheet format

A special sheet format is to be developed to collect data during the monitoring process. Generally, the sheet format consists of three main parts: i) general information about the sampling location/site; ii) ground cover information at the quadrat or plot level; and iii) all possible information on plant species.

7.3.7 Data entry

Data entry onto the computer should be accomplished in a simple and straight-forward format to facilitate computation of the desired variables and parameters.

7.3.8 Required parameters

The following variables/parameters and indices will be computed to accomplish the objectives of the proposed monitoring programme:

- Coverage of total vegetation, forage species, key forage species and non-forage species
- Density of mature and seedlings of perennial key forage species (i.e. herbs, shrubs, trees)
- Shannon Diversity Index
- Raunkiaer's life forms
- Biomass production of total accessible vegetation and key forage species.

7.3.9 Statistical analysis

The permanent transects will serve as sampling units, while the quadrats will be systematically placed along transects and will serve as sub-samples. The appropriate statistical analysis tests for the targeted parameters are summarized in Table 13.

TABLE 13.
STATISTICAL ANALYSIS TESTS FOR THE TARGETED PARAMETERS SUMMARY

Years	Variables/Parameters			
	Cover	Frequency	Density	Biomass
2012*	DS	DS	DS	DS
2012 & 2013	P t test	Chi-square	P t test	P t test
2012, 2013 & 2014	RM	Chi-square	RM	RM
2012, 2013, 2014 & 2015	RM	Chi-square	RM	RM

* year of baseline study, DS: descriptive statistics, P t test: paired t test, RM: repeated measure.

7.4 A comprehensive study on *Juniperus phoenicia* in Dana Reserve

The RSCN research and survey section has contracted a professor to conduct the comprehensive study, with the SUMAMAD project co-financing the study, as it costs more than the allocated SUAMAMAD budget. The study was carried out during the spring of 2012, and the draft report was received by the research

and survey section, which was delivered as a final report at end of December 2012 after amendments.

7.4.1 Soil study

Phoenician juniper (*Juniperus phoenica)* is found throughout the southern highlands of Jordan. It occurs in several areas including the Dana Biosphere Reserve, which was established to protect a representative sample of the Juniper vegetation type in Jordan. This species covers highland areas in the eastern part with an elevation above 700 m. Juniper status is declining in the reserve due to several factors, such as climatic conditions and drought, woodcutting and grazing activity, which may contribute to the dieback phenomenon in the reserve. The reasons behind the juniper dieback have not yet been studied, but many factors can be investigated to understand this phenomenon, such as the water status of the soil. Juniper dieback is a fact and it might increase over time, thus, a survey is needed to better understand this phenomenon so as to act accordingly.

This study will be carried out to examine factors affecting juniper dieback in the Dana reserve.

Materials and methods

Dana Biosphere Reserve and nine plots were assigned in three different locations including one in Al-Barrah outside the reserve boundary. One extra plot was assigned in an area where a water harvesting and irrigation trial will be conducted. Each plot was located with an area of 250 m^2, covering the most sensitive areas with juniper trees, where some suffered dieback while others exhibited regular growth without stress.

Soil analysis

Soil samples were taken from ten different plots around the reserve. Samples were taken from inside and outside the plot at 30 cm depths. An auger and a shovel were used. The soil samples analysis showed that the soil pH was within the range of 7.33 and 7.70. The electrical conductivity (EC) was within the range of 0.24 and 0.52, except plot number 4 whose EC values were high 3.54 with high salinity inside the plot compared to the outside. The nitrogen percentage was in the range 0.045 to 0.196%. In general, most of the samples outside the plots were lower in nitrogen percentage compared to the inside, which might reflect the high organic matter and total digestible solids (TDS) inside the plots showing a fertile soil.

TABLE 14.
SOIL ANALYSIS OF THE 10 PLOTS IN DANA RESERVE AND IN AL-BARRAH

Plot-Position	PH	Ec (dS/m)	TDS	N %
DANA 1-in	7.61	0.464	296.96	0.149
DANA 1-out	7.33	0.408	261.12	0.148
DANA 2-in	7.41	0.366	234.24	0.105
DANA 2-out	7.42	0.39	249.6	0.186
DANA 3-in	7.47	0.403	257.92	0.102
DANA 3-out	7.41	0.453	289.92	0.0451
DANA 4-in	7.45	3.542	2266.88	0.187
DANA 4-out	7.43	0.356	227.84	0.073
DANA 5-in	7.53	0.298	190.72	0.0895
DANA 5-out	7.61	0.265	169.6	0.0617
DANA 6-in	7.44	0.314	200.96	0.1035
DANA 6-out	7.61	0.287	183.68	0.073
Al-Barrah 7-in	7.5	0.498	318.72	0.183
Al-Barrah 7-out	7.55	0.276	176.64	0.075
Al-Barrah 8-in	7.48	0.438	280.32	0.196
Al-Barrah 8-out	7.65	0.239	152.96	0.066
Al-Barrah 9-in	7.38	0.518	331.52	0.131
Al-Barrah 9-out	7.7	0.262	167.68	0.097
H7-in	7.65	0.502	320.60	0.193
H7-out	7.45	0.277	176.7	0.085

8. Recommendations for sustainable dryland management

- To build on the success story of grazing management planning at Al-Barrah area, replicating it in other sites in Dana Biosphere Reserve or other reserves run by RSCN.
- Introduce more income-generating projects to reduce pressure on the natural resources and to sustain the natural environment of the drylands.
- To study the impact of the project on the natural resources beyond the project life cycle.
- To study the different grazing schemes on different biogeographical zones within Dana Biosphere Reserve, and their impact on natural resources.
- To study the impacts of climate change and the grazing scheme used at Al-Barrah and their effects on the productivity and sustainability of the natural pastures.

9. Research institution and team composition

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10. National seminars

Four national seminars were held within the implementation framework of SUMAMAD Phase I, whose purpose was to inform stakeholders, allowing them to participate and contribute towards the development of the community-based grazing management plan.

The 2009 seminar took place on 25 December in DBR and targeted national level decision-makers. The objective of the seminar was to garner more support for the project at the national level, and also to inform the decision-makers of the work carried out in 2009.

The 2010 seminar was held on 22 November in DBR to discuss the progress and findings of the research conducted in 2010, which was designed for both the academics who participated in the work and the surveys, and for local communities and the livestock owners. Forty people attended the seminar (twenty-five livestock owners, eight from RSCN and Dana

staff, two professors from Jordanian universities, and five decision makers from Tafilah governorate). The workshops and seminars played a major role in presenting the results of the team's work and the platform for the area's future plans, as well as work plans of the projects so as to discuss some of the management scenarios for the area and its benefits to the community, including enriching the biodiversity of the reserve.

In the presence of Tafilah's governor and the Minister of Agriculture, another public meeting was held in Tafilah governorate in October 2010 for all the stakeholders in Tafilah. For the first time, the livestock owners in Dana were recognized as an institutional body and were invited to participate in the meeting; their representatives were very effective in representing the work of SUMAMAD in front of all the communities and stakeholders and talking about their priorities. This meeting was very important in ascertaining the community members' views and opinions towards the work carried out under SUMAMAD. The meeting was very positive and inspired other community members to start asking how they can organize grazing activities in Dana with the cooperation of local communities.

The 2011 seminar was held on 30 November to discuss the progress and implementation of the grazing management plan.

The 2012 seminar was held in September 2012 to present all the work carried out during the past year and the four years of implementation so as to share the lessons learned and to officially announce the end of the SUMAMAD project.

11. References

Abu-Zanat, M.M.W. 2009. Socioeconomic characteristics of stockowners in Al Barrah area. Sustainable Management of Grazing Resources of Al Barrah Area in Jordan, Sustainable Management of Marginal Drylands Project (SUMAMAD), The Royal Society for the Conservation of Nature, Amman, Jordan.

Al-Eisawi, M.H.D. 1998. *Field Guide to wild flowers of Jordan and neighboring countries*. Jordan Press Foundation 'Al Rai', Amman, Jordan.

Bonham, C.D. 1989. *Measurements for Terrestrial Vegetation*. John Wiley and Sons, USA.

Clawson, W.J., N.K. McDougald, and D.A. Duncan. 1982. *Guidelines for residue management on annual range*. University of California, Division of Agriculture and Natural Resources, Leaflet No. 21327.

Cook, C.W. and J. Stubbendieck. 1986. Range research: basic problems and techniques. *Society for Range Management*, Denver, Colorado.

Dunne, J. 1989. Cryptogamic soil crusts in arid ecosystems. *Rangelands*, Vol. 11, No. 4, pp. 180–185.

Kent, M. and P. Coker. 1999. *Vegetation description and analysis: a practical approach*. John Wiley & Sons, New York.

Krebs, J.C. 1998. *Ecological Methodology*. Addison Wesley Longman Inc., pp. 620.

Magurran, A.E. 2004. *Measuring biological diversity*. Blackwell Science, Oxford.

Raunkiaer, C. 1934. *The life forms of plants and statistical plant geography*. Clarendon Press, Oxford, pp. 632.

Management Practices for Rehabilitation of Degraded Dryland Ranges, Lal Sohanra Biosphere Reserve

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Executive Summary

The extent of marginal drylands in Pakistan amount to 11 million hectares. These drylands are barren due to low rainfall and water scarcity, and groundwater is mostly saline. There are four main economic activities in the drylands of Lal Sohanra Biosphere Reserve, comprising livestock rearing, labouring, handicrafts, and agriculture on the periphery of the desert land. The rangelands are degraded because they are poorly maintained with an uncontrolled grazing system resulting in overgrazing. Consequently, there is an urgent need to manage the rangelands using scientific knowledge, which will provide fodder to livestock throughout the year and support more livestock per unit area.

With financial assistance from the Sustainable Management of Marginal Drylands (SUMAMAD) project, a natural degraded rangeland site was selected for rehabilitation at Hyderwali in the vicinity of the Lal Sohanra Biosphere Reserve.

Project activities began in early 2009 and were mainly focused on improving the carrying capacity of rangelands. The management strategies adapted include:

- ***Rotational grazing system:*** The rangeland area was divided into compartments – one compartment was used for grazing, while the other was left for sprouting. This strategy prevents rangeland degradation, while ensuring a sustainable output.

- ***Application of irrigation:*** The rainfall in the area is too low to obtain a greater potential yield from the rangelands, thus an irrigation supplement was introduced. Four irrigations (each of 30 mm) were applied using sprinklers during the year.

- ***Reseeding of local grasses and bushes:*** Due to prolonged drought spells, palatable species of grasses in the Cholistan desert have almost vanished. In order to rehabilitate them, seeds of palatable grasses were spread during the monsoon season in both years (2009–2010).

The first two years of the SUMAMAD project focused on the management of the rangelands and the grazing system. Later an experiment was conducted to grow fodder crops at the study site. Mixed cluster bean (Guar) and millet (Bajra) crops were grown in the month of July 2011 on a total area of about 2 hectares. In addition to the 132 mm of rainfall that occurred during the crop season, an irrigation supplement of 75 mm was applied using a sprinkler system. A fodder yield of 19.03 tonne/ha was obtained, which is 13 per cent more than the yield obtained from the flood irrigation system. The preliminary results of the study have shown that the carrying capacity of the rangelands is increasing progressively, and by the end of the fourth year of the study an increase of more than 700 per cent was recorded. The availability of grasses has led to a reduction in migration from the project's vicinity. Alternate livelihood activities have been initiated such as rearing of free-range chicken, while an exhibition during the SUMAMAD national seminar encouraged people to take up and produce more handicrafts. As a result of the interventions made by SUMAMAD, the Cholistan Development Authority has submitted a mega-project to the provincial government of Punjab. A core group has been organized to prepare guidelines for a policy draft on the sustainability of drylands. Primary conclusions and recommendations of the study reveal the following:

- Research results indicate that the protection of natural grazing lands from the free grazing of

livestock and irrigation with sprinklers during dry periods contribute towards increasing vegetation canopy cover, vegetation species, and vegetation biomass production.

- The ranges should be protected from free grazing, and a controlled rotational grazing system should be adopted in order to maintain the sustainability of the ranges for higher carrying capacity per unit area.
- On scientific grounds, the desert land may be allocated to the local population to promote livestock.
- Livestock may be replaced with free-range chicken to avoid over-exploitation of rangelands.

1. Introduction

Rangelands cover about 40 per cent of the Earth's land surface; the same ratio found in Pakistan. Vast desert plains are present in three provinces: Baluchistan, Punjab and Sindh, and the major deserts of the region are Thar, Thal, Cholistan and Kharan. The productivity of rangeland, pasture and forage cropping areas depends directly on the plants that grow there. Besides providing food for livestock, these plants have other uses such as turf, biofuel, human nutrition and medicine.

In Pakistan, rangelands are a major source of livestock feed in the arid regions, but due to low rainfall and overgrazing in recent years, the carrying capacity of these rangelands has fallen to 10-50 per cent of their potential. Consequently, livestock (dependent on grazing) is under severe nutritional stress. People in desert areas are dependent on livestock rearing; over 100 million heads of livestock are being supported by rangelands. The importance of rangelands to the national economy can be measured by the fact that more than 87 per cent of the total population of Baluchistan province derives its livelihood – directly or indirectly – from livestock rearing. The uncontrolled pattern of grazing in the area is causing serious damage to palatable vegetation, which is important as these species, which are preferred by animals, are the first to suffer. The pastoralists have increased their herd size beyond the carrying capacity of the available resources. This over-population of livestock, without range maintenance, causes overgrazing. The animals consume forage vegetation faster than it can regenerate, eventually leading to the disappearance of vegetation in the area. With such degraded ground cover, soil erosion becomes a serious problem and any chance of restoring the range becomes remote because of the massive loss of topsoil. According to Sharma (1997), the high livestock numbers in the arid regions causes overgrazing, which in turn results in reduced infiltration, accelerated runoff and soil erosion.

Phase II of the SUMAMAD project began in 2009 with the collaboration of UNESCO, UNU-INWEH and the Flemish Government of Belgium. The Pakistan Council of Research in Water Resources (PCRWR) is one of the partner research institutions, with Pakistan being one of the target regions. Thematic areas of the project include land degradation, desertification, biodiversity, sustainable development, biosphere reserve management, water resources management, agriculture, climate change scenarios, dryland policies, and poverty alleviation. In Pakistan, a research study was designed for this five-year project to rehabilitate degraded rangelands and provide alternative livelihoods for local people by adapting to different management strategies.

2. Background of study area

Lal Sohanra Biosphere Reserve is located in Cholistan desert. This is the second largest desert in Pakistan located in the southern part of the Punjab province. Its total surface area covers about 2.6 million hectares and it is one of the driest and hottest regions in the country. The temperature rises rapidly from April onwards, reaching its peak in late May or June. During this period, hot and dry winds blow throughout the day and this hot spell is occasionally interrupted by dust storms. The mean relative humidity falls below 32% due to the high temperature, which normally exceeds 45°C, sometimes rising to 50°C. Annual rainfall varies between 100–250 mm.

The soils of the area are formed from two types of materials: river alluvium and aeolian sands. The alluvium consists of mixed calcareous material derived from the igneous and metamorphic rocks of the Himalayas, deposited by the Sutlej River and the abandoned Hakra River – most probably during different stages in sub-recent periods. The aeolian sands are derived from the Rann of Kutch, the sea coast, and partly from the lower Indus Basin. The material was carried from these sources by the strong southwesterly coastal winds. Main soils types of dune lands are sandy, loamy and clayey.

The human population, projected in 1991 and based on the 1981 census, was 97,000, with a population density of 3.73 individuals per km², (FAO, 1993). The deep interior of the desert is more sparsely populated than the peripheral zone. Semi-permanent and nomad inhabitants roam the length and breadth of the desert on the continuous look out for forage for their livestock, and more importantly for drinking water. According to figures provided by Divisional Forest Officer, Cholistan Range Management Division, during May 1994, total livestock in Cholistan was 262,430 (63,095 cattle; 114, 421 sheep; 72,726 goats and 12,188 camels) with generally low annual growth: 2.7% for cattle and 3.4% for goats, and a slight decline in the number of sheep and camels. In the last thirty years (1964–1994), the combined average growth remained less than 1%.

The primary source of water is rainfall, which is low and sporadic, causing drought and famine in the area, reducing grazing lands, increasing livestock mortality, and adding untold misery to the human population.

Water harvesting is the process of collecting natural precipitation from a prepared or natural watershed for a number of beneficial uses. People of the desert collect rainwater in natural depressions or human-made ponds known locally as tobas. There are about 1,500 small tobas in Cholistan desert, though they are not properly designed. The size and storage capacity of each toba varies between 1,000 and 1,500 m³. The total water storage capacity on average is about 1.7 million m³, whereas the annual drinking water requirement for the population is about 7 million m³. These small tobas, as well as some dug wells in the freshwater zone, meet drinking water requirements for 3–4 months, after which people migrate along with their livestock toward irrigated areas where they remain until the next rainfall.

Since 1983, Cholistan – a protected forest – is managed as a protected area for wildlife under the protection, preservation, conservation and management provisions of the Punjab Wildlife Act 1974. A part of the Cholistan (6,533 km²) has been declared a wildlife sanctuary. The remaining 20,184 km² is managed as a wildlife reserve. According to the legislation, hunting is permitted in the wildlife reserve with a special permit, whereas all forms of population exploitation such as hunting, poaching, killing, capturing or netting is strictly prohibited in the wildlife sanctuary.

The habitat is generally semi-desert to desertic in nature. Microhabitats support a variety of wildlife species, especially birds. Some species found in Cholistan have enormous game value and are regularly exploited by hunters and poachers – local as well as from abroad. The most important of these species are the chinkara antelope, nilgai antelope, blackbuck, bustard, great Indian bustard and the imperial sandgrouse. The houbara bustard is a globally vulnerable species and is currently a subject of debate among conservationists. This wide-ranging migratory bustard is highly prized as a quarry by falconers from all over the world wherever it is found. Royal hunting safaris from the Gulf States visit Cholistan every winter to hunt houbara bustard. A multi-national conservation strategy is therefore urgently required to save the species for the future.

Vegetation in Cholistan is characterized by xerophytic adaptations, largely dependent on the erratic rainfall. In different studies, 64 plant species belonging to 24 families were recorded. The biggest family is Poaceae with 19 recorded grass species. Dominant plant species include *Aristida adscensionis*, *Cymbopogon jwarancusa*, *Ochthochloa compressa*, *Lasiurus scindicus*, *Sporobolus ioclados*, *Cenchrus biflorus*, *Aeluropus lagopoides*, *Calligonum polygonoides*, *Crotalaria burhia*, *Suaeda fruticosa*, *Salsola baryosma*, *Leptadenia pyrotechnica*, *Haloxylon recurvum*, *Haloxylon salicornicum*, *Dipterygium glaucum*, *Zaleya pentandara* and *Trianthema triquetra*.

3. Main features and challenges of the study site

The degraded natural rangeland site was selected for rehabilitation in the vicinity of Lal Sohanra Biosphere Reserve at Hyderwali in the Cholistan desert. There are four main economic activities in the drylands of Lal Sohanra Biosphere Reserve, which are livestock rearing, labouring, handicrafts and agricultural activities on the periphery of the desert land. About 70 per cent of livelihood needs depend on livestock rearing, 20 per cent on labour, 8 per cent on agricultural activities, and 2 per cent on handicrafts. The non-availability of potable water for human and livestock consumption is a severe problem in the area. PCRWR has made efforts to mitigate this threat by instigating rainwater harvesting systems, and by installing deep tube wells in good quality water zones and desalinization plants. The land is left for grazing only and the rangelands have become very poor as a result of the uncontrolled grazing system. Furthermore, there is no established maintenance mechanism at the government or NGO level. People, along with their livestock, are therefore compelled to migrate from the drylands towards settled areas for most months of the year. Migrations cause the annual loss of billions of rupees in the form of livestock mortality, feed expenses, low productivity and crop damage in irrigated areas, which occasionally leads to social conflict and disputes. There is therefore an urgent need to manage the rangelands – based on scientific knowledge – to ensure the availability of fodder for the entire year. To increase the livestock population and production in the area, basic commodities such as the availability of drinking water and good rangelands need to be ensured.

The availability of water and fodder in the drylands will further ensure human settlement, as well as facilitate and manage health and education facilities for the nomadic populations. The study embedded within the SUMAMAD project is a step forward in mitigating the drought effects of drylands. Activities of the SUMAMAD project sought to:

- Rehabilitate degraded rangelands through the management of land, water and vegetation resources.

- Halt further rangeland degradation by adopting protective measures to enhance carrying capacity.
- Introduce irrigation to rangelands through sprinkler systems during the dry season, using harvested rainwater or usable groundwater to obtain maximum biomass production.
- Enhance livestock production in the drylands by providing more fodder per unit area and increasing carrying capacity.
- Increase and introduce alternative income generation sources for local people residing in the drylands so as to improve their quality of life.

Figure 1.
Site selected and fenced off for rangeland development.
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4. Project activities

4.1. Fostering scientific drylands research

The chosen study site for activities of phase II of the SUMAMAD project is Hyderwali, which lies in the vicinity of the Lal Sohanra Biosphere Reserve in the Cholistan desert. During the initial two years of the project (2009 and 2010), activities were focused on the restoration and rehabilitation of degraded rangelands, whereas in 2011-2013, the introduction of drylands agriculture was included among the activities.

4.1.1. Restoration and rehabilitation of degraded rangelands

The Cholistani people are dependent on the rangelands for their livelihood; however, the potential biomass of the rangelands has not been realized due to low intensity of rainfall. During 2010–12 the rainfall measured at between 96 to 145 mm (Table 1) at the study site, occurring mostly during the monsoon season (July-September), was insufficient to sustain ranges without irrigation. In a scenario without irrigation supplement it would

TABLE 1.
RAINFALL AND IRRIGATION (MM) SUPPLEMENT DURING THE YEARS 2010–2012

S #	Source	Months												Total
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	Rainfall 2010	-	-	-	-	-	6	41	60	10	-	-	-	117
	2011	-	9	4	-	-	-	15	89	28	-	-	-	145
	2012	-	-	-	-	-	-	-	30	67	-	-	-	97
2	Irrigation 2010	-	30	30		-	-	-	-	-	30	30	-	120
	2011	-	30	30	-	-	-	-	-	-	30	30	-	120
	2012	-	30	30	-	-	-	-	-		30	30	-	120

be impossible to achieve rangeland development. The rainwater harvesting facility and tubewells for groundwater exploitation are now available at the study site.

Rainwater-harvesting facility: In spite of low rainfall, about 72,000 m^3 of rainwater was harvested each year in the vicinity of the study site. With financial assistance from the SUMAMAD project, a pipeline was installed to transport rainwater from the reservoir to the rangeland study site.

Groundwater: Groundwater quality in most parts of Cholistan is poor. In certain places, levels of total dissolved solids (TDS) are as high as seawater. However, the water quality in the abundant bed of the old Hakra River is within safe limits. PCRWR installed a tube well at the selected site in the vicinity of the old riverbed where the groundwater quality in terms of TDS is within safe limits. However, its residual sodium carbonate (RSC) is on the high side (the maximum permissible limit is 1.25 epm).

Caution is advised when using high RSC water, as it can have adverse effects on the soil. Year-on-year results of water quality parameters from the different water sources are presented in Table 2.

Figure 2.
Tubewell installed by PCRWR at the research station
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On average, two irrigation supplements (each of about 30 mm) of groundwater were applied in the

TABLE 2.
QUALITY OF WATER SOURCES USED FOR IRRIGATION

S#	Water quality parameter	Water sources								
		Groundwater			Rainfall			Rainwater (stored)		
		2010	2011	2012	2010	2011	2012	2010	2011	2012
1	EC (ds/cm)	890	830	863	20	20	27	480	380	410
2	TDS	570	557	552	13.00	13	17	303	243	262
3	pH	8.10	8.49	8.2	7.50	7.5	7.5	8	7.5	7.8
4	Ca+Mg (meq/lit)	1.21	0.79	0.1	0.15	0.15	0.21	2.99	1.39	2.42
5	Na (meq/lit)	7.93	7.6	7.7	0.05	0.05	0.048	1.59	2.0	1.55
6	K (meq/liters)	0.15	0.125	0.25	0.00	0	0.01	0.19	0.29	0.11
7	CO_3 (meq/lit)	0	0.97	0	0	0	0	0.05	0	0
8	HCO_3 (meq/lit)	7.2	7.0	7.7	0.10	0.1	0.15	2.7	2.4	2.5
9	Cl (meq/liters)	0.8	0.93	0.68	0.10	0.1	0.1	1.03	0.53	0.86
10	SO_4 (meq/lit)	1.34	1.27	1.25	0.00	0	0.02	1.02	0.64	0.69
11	SAR	10.20	6.97	10.8	0.18	0.18	0.14	1.30	2.39	1.4
12	RSC (epm)	5.99	7.18	6.6	Nil	Nil	Nil	Nil	1.0	0.08

months of February and March in each year when rainwater was not available in the storage ponds. From July to September, there was sufficient rainfall in the area so irrigation was not used. As a result of the rainfall, there was sufficient water stored in the reservoirs such that the two irrigation supplements in October and November were applied from stored rainwater.

The principle behind irrigation is to satisfy the rainfall gap during the sprouting season of grasses. The months of April, May, June, December and January do not fall in the sprouting season and therefore irrigation was not used, even when there was no rainfall during these months. The purpose of these research activities is to develop strategies and guidelines that can be used by the common farmer. The uncontrolled experimental area (site 3) was solely dependent on rainfall, which was used for the purpose of comparison. The rainfall and irrigation schedule for each year is presented in Table 2.

Vegetation species and cover: In 2009, an area of 10 ha was fenced, which was increased to 20 ha in 2010. The dominant natural vegetation species in the area include *Lasiurus sindicus* (Gorkha), *Calligonum polygonoides* (Phog), *Haloxylon salicornicum* (Lana), *Aristida depressa* (Lumb), *Dipterygium glaucum* (Phail), *Eleusine compressa* (Chimber) and *Aerva javanica* (Bui). Due to long spells of drought and overgrazing practices, palatable grasses almost disappeared from the rangelands. Thanks to financial assistance provided by the SUMAMAD project, the reseeding of grasses was carried out in the controlled grazing plots together with irrigation. Table 3 shows that total vegetation canopy cover in February 2009 (before the start of SUMAMAD activities) was 16–19%. With the start of management activities (controlled grazing, reseeding and irrigation), the vegetation cover has been progressively increasing.

By the end of 2012, it had reached 66 per cent. Similarly, palatable biomass production has increased by more than 700 per cent compared to uncontrolled plots (Table 4).

Figures 3 and 4.
Rangeland under control grazing
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TABLE 3.
CANOPY COVER OF THE VEGETATION

Location	Vegetation Cover (percentage)							
	Feb 2009	Oct 2009	March 2010	Oct 2010	March 2011	Oct 2011	March 2012	Oct 2012
Site 1 (controlled grazing)	18	31	35	58	41	62	56	66
Site 2 (controlled grazing)	19	28	33	52	39	59	55	60
Site 3 (un-controlled grazing)	16	12	14	21	15	19	16	20

TABLE 4.
VEGETATION BIOMASS

Site No.	Biomass (Tonnes/hectare)											
	Palatable			Browsable			Unpalatable			Total		
Year	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
1	7.27	7.67	7.38	7.06	8.10	8.73	1.35	0.95	1.07	15.68	16.72	17.15
2	5.05	7.06	7.51	10.4	9.03	9.68	1.60	1.34	1.28	17.05	17.38	18.47
3	0.96	1.02	0.99	8.45	8.0	8.02	0.57	0.98	0.85	9.98	9.99	9.85

4.1.2 Introduction of dryland crops

Agriculture is the backbone of Pakistan's economy, but for several reasons production is not increasing proportionally to the human population, even though demand for food, milk, meat, fodder and fuel is increasing day-by-day. To cope with these food problems, it is essential to convert desert lands for crop production through the sustainable use of natural resources. Under the financial assistance of the SUMAMAD project, an experiment was conducted to grow fodder crops at the study site. Cluster bean (Guar) and millet (Bajra) crops were grown in the month of July 2011 on a total area of about 2 ha. An irrigation supplement of 75 mm was applied through a sprinkler system in addition to 132 mm of rainfall, which occurred during the crop season. The fodder yield was weighed at five randomly selected sites (each of 4 m^2) in the month of October 2011. The weight of green fodder for both crops was measured separately for each site and recorded (Table 5). The average yields of millet and guar obtained from 1 ha were 15.15 and 4.13 tonnes, respectively (assuming half the area for each crop, the average yield of mixed fodder from both crops was 19.03 tonne/ha).

The yield results were compared with a survey conducted by an expert team from the Japan International Cooperation Agency (JICA) in some areas of Pakistan during the months of October to November 1999, to observe fodder production at various research institutes as well as local farms. According to the survey report, which was submitted to the National Agricultural Research Centre (NARC), average yields of millet and guar in isolation were 23.5 tonne/ha and 9.5 tonne/ha respectively. If this yield of millet and guar is mixed, this amounts to 33 tonnes per 2 ha, which is about 16.5 tonnes/ha. The yield obtained from virgin desert land using a sprinkler system is 13 per cent more than the yield obtained from the flood irrigation system.

TABLE 5.
CROP YIELD (GREEN FODDER)

Site #	Green Fodder Yield (Tonne/ha)		Total (Tonne/ha)
	Millet	Guara	
1	15.48	3.80	19.28
2	13.68	3.65	17.33
3	16.57	4.13	20.70
4	12.95	3.95	16.90
5	17.05	3.85	20.90
Average	15.15	3.88	19.03

Figures 5 and 6.
Fodder Crops (millet and cluster bean) at the study area
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4.2 Preparation of policy-relevant guidelines for decision-makers in drylands

On the occasion of the SUMAMAD national seminar in 2009, a core group was set up to prepare guidelines for decision-makers in drylands. The group was composed of the following dryland stakeholders:

- Cholistan Development Authority (CDA)
- Pakistan Council of Research in Water Resources (PCRWR)
- Cholistan Institute of Desert Studies (CIDS), the Islamia University of Bahawalpur
- Forest Department, Provincial Government of Punjab
- Three representatives of the local Cholistani people

The leading role was given to CDA, while PCRWR was given an organizational role. During the meetings, which were held from time to time during the project period, the group identified the following major areas to be highlighted in the context of the sustainable management of drylands:

- Introduction of Resource Conservation Technology, including the use of high efficiency irrigation for rangelands development.
- Public awareness on adopting the controlled grazing system.
- Constitution of a rangelands decision-making forum to ensure the welfare and rational use of rangelands, including representatives from the departments concerned (Cholistan Development Authority, PCRWR, Forest Department), as well as end users.

By adapting the above concept, the Cholistan Development Authority submitted a project for funding to the provincial government of Punjab. Thus, strategies identified in the SUMAMAD project will be scaled up.

4.2.1 Review of core group meeting 2011

In each year following the national seminar, a meeting of the core group was also convened at the same venue to review policy-related issues, achievements, and further targets. Members of the Provincial Assembly of Punjab, representatives of the Cholistan Development Authority, PCRWR, the Forest Department, the Cholistan Institute of Desert Studies (CIDS) and local persons attended the meeting. An impressive response from the local people was obtained to follow up the guidelines presented in the meetings. Local persons have become aware that rangeland conservation was not only the responsibility of governmental organizations but equally their own responsibility.

The core group appreciated and supported the efforts taken by the local people. It was also decided that livestock agricultural activities would also be promoted in dryland areas. In this regard, the SUMAMAD team will provide the technical guidelines for cropping pattern and management strategies. The SUMAMAD team leader shared the results of the experiments on rangeland management and the cultivation of fodder crops. The people thanked the SUMAMAD project for establishing valuable guidelines to promote livelihood activities in the drylands.

4.3. Promoting sustainable livelihoods in drylands

Four economic activities in the drylands of Lal Sohanra Biosphere Reserve have been identified: livestock rearing, labouring, handicrafts and agriculture on the periphery of desert land. The major livelihood of the drylands population is livestock rearing with forage also a basic requirement in the area. The SUMAMAD project has provided the technology to enhance forage production in the project vicinity. With the financial support of SUMAMAD project, the following activities for the sustainable livelihood of the Cholistani people have been promoted:

I. *Enhancement of forage for sustainable livestock growth and production*. Fodder is a basic requirement for livestock rearing. For the first time in the desert area, successful trials for growing fodder crops (guar and millet) on sprinkler irrigation were conducted. The results were encouraging. Multiplication of this technology can bring a revolution to the desert by increasing livestock products and enhancing the livelihoods of the people.

II. *Improvement in agriculture activities*. There is no water source to support agriculture so the land is utilized only for grazing. PCRWR has installed some tubewells in the bed of the old Hakra River. Under the financial assistance of SUMAMAD, people are being encouraged to grow low delta crops to enhance their income. Farmers were supported to grow mustard crops near their toba. The number of farmers and the areas under cultivation can be increased with continuous support.

III. *Promotion/proper marketing of local handicrafts and livestock by-products*. The women of Cholistan make excellent handicrafts, but their access to the market is limited. As a result they do not realize the proper value of their products. Under the assistance of the SUMAMAD project, PCRWR arranged exhibitions of their handicrafts. Many products were sold on this occasion, a number of which realized attractive prices. Moreover, arrangements were made for handicraft dealers to visit the Cholistan desert in order to attract better marketing of their products.

IV. *Rearing free-range chicken*. One of the major reasons of rangeland degradation is the over-population of livestock. Biomass production under natural conditions could not meet the fodder requirements of the ever-increasing population of livestock. According to SUMAMAD activities in China, in order to stop grassland degradation, researchers innovatively replaced cattle and goat with poultry to explore a win-win approach, ensuring both ecological conservation and economic development. They have investigated the growth, development, and feed demand of free-range chicken.

To test the above hypothesis, a free-range chicken farm with about 400 chickens was established in 2012 at the PCRWR Field Research Station in Dingarh. Here the growth, development and feed demand of free-range chicken was analysed under local

environmental conditions. Initial results are very encouraging from the growth and survival point of view. It can be concluded that free-range chicken is the best alternative livestock to cow, sheep and goat.

Figures 7 and 8.
Free range chicken reared at the field station
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4.4. National seminar

A national seminar on 'Management Practices for Rehabilitation of Degraded Dryland Ranges, Lal Sohanra Biosphere Reserve, Pakistan' was organized every year during the project period at field stations and in Bahawalpur city with the financial assistance of SUMAMAD. About 200-300 women and men from the local community participated, and private and public organizations attended the seminar every year.

The purpose of the events was to present issues to the local people, as well as introduce remedial measures taken with the financial support of the SUMAMAD project. The events started with the presentation by the SUMAMD team of the aims and objectives, the achievements of the respective year, and the future plan of the SUMAMAD project. This was followed by presentations from representatives of the Cholistan Development Authority, the Forest department, and the Cholistan Institute of Desert Studies on the importance of rangelands, highlighting the different livelihood options. The local community also had the opportunity to present their concerns. The representative of the provincial government was invited to convey the project activities, as well as the concerns of the local people.

Figures 9 and 10.
National Seminar 2012 © Zamir Ahmed Soomro

4.4.1 Results obtained and preliminary recommendations

- Following the SUMAMAD activities the carrying capacity of the rangelands has increased by up to 700 per cent.
- The yield of mixed fodder crops (millet and guara) obtained was 19.03 tonnes/ha.

- Water use with the application of irrigation from the sprinkler system on fodder crops obtained 12.77 kg/m^3 of green fodder.
- The use of the sprinkler irrigation system should be encouraged in desert areas for fodder crops to increase livestock production and meet the milk and meat requirement of the country.
- Free-range chicken is the best livestock alternative (among cow, sheep and goat).
- Migration in the project vicinity has been reduced.
- People have been encouraged to increase handicrafts production, sales of which at the SUMAMAD exhibitions obtain a higher value.
- The Cholistan Development Authority has submitted a mega-project based on SUMAMAD activities.
- A core group was set up to prepare and submit guidelines/policy draft to the government.

4.4.2 Preliminary recommendations to decision-makers

- The research results indicate that the protection of natural grazing lands from uncontrolled grazing by livestock, and irrigation by sprinkler during the dry period contributes towards increasing vegetation canopy cover, vegetation species and vegetation biomass production.
- The ranges should be protected from uncontrolled grazing, and a rotational grazing system should be adopted to increase more biomass production and obtain greater carrying capacity per unit area.
- The land of the Cholistan desert may be allocated to local people to promote dryland agriculture.
- Local people should be encouraged to replace livestock with poultry.
- A high-efficiency irrigation system (sprinkler and trickle) may be subsidized in the desert area.

4.4.3 Problems and challenges

- Extreme aridity: the predominantly sandy nature of the soil and topography prevent arable use of the area. A rough levelling of hummocks was made to spread and mix the roots and shoots cuttings of the shrubs in soil. Consequently, vegetation growth was dense and mitigated the effects of aridity.
- High-speed wind storms (mostly during the day) prevent the use of sprinklers, except at night.
- Due to a long spell of drought, most vegetation has disappeared and local grass seeds have become very rare. Under the financial assistance of SUMAMAD, seeds of grasses were procured from other areas.
- Free-range chicken is the best alternative livestock, but the Cholistan people are nomads, which inhibits its introduction. To overcome this problem, government incentives are needed.

5. Biblography

FAO. 1993. *Pakistan-Cholistan Area Development,* Report No, 59/53 ADB-PAK 58 Final Version. Food and Agriculture Organization of the United Nations, Rome.

Sharma, K.D. 1997. Assessing the impact of overgrazing on soil erosion in arid regions at a range of spatial scales. In: Human Impact on Erosion and Sedimentation, Proceedings of the Rabat Symposium, April 1997). *International Association of Hydrological Sciences* Publ. No. 245.

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Watershed of Zeuss-Khoutine and Bou-Hedma Biosphere Reserve

By M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

Institut des régions arides

Tunisia

1. Main dryland challenges at the project site

1.1. Introduction

Desertification threatens around 52 per cent of the land area of Tunisia that is suitable for agriculture, forestry and pasture farming (MEAT, 1998). Incompatible forms of land use have resulted in soil degradation and salinization, and water and wind erosion, triggering a loss in land productivity.

Tunisia has an ancient tradition of combating land degradation and desertification. In fact, for a long time the country has been seeking solutions to these problems through its own means and with international support. Moreover, investments and organized efforts to combat desertification began soon after independence within the framework of the various strategies for the protection and management of natural resources, and finally with the implementation of the National Action Programme to Combat Desertification (NAP-CD) ratified in 1998 as part of the United Nations Convention to Combat Desertification (UNCCD). The UNCCD stated that combating desertification could not be limited to only technical measurements but must, on the contrary, be considered as a complex unit of coherent actions that take into account its socioeconomic dimensions, as well as biophysical and environmental aspects. In fact, chapter 12 of Agenda 21 and Article 16 of the UNCCD recommends developing desertification control dashboards to enable a better understanding of the phenomenon, and for efficient joint action by decision-makers and stakeholders to curb its unfavourable effects. It is for this reason that the UNCCD signatories admitted the importance of controlling the monitoring/evaluation programmes to combat desertification, and that the national focal point (NFP) would have a global vision of the process of implementation of these programmes.

The decentralized implementation of NAP, by placing more importance on the role of local actors, strongly challenges the national decision makers to take up the challenge of decentralization, dialogue, and the coordination of actions between the various actors at the national, sub-national and local levels.

The Sahara and Sahel Observatory (OSS) developed an environmental monitoring programme that aims to

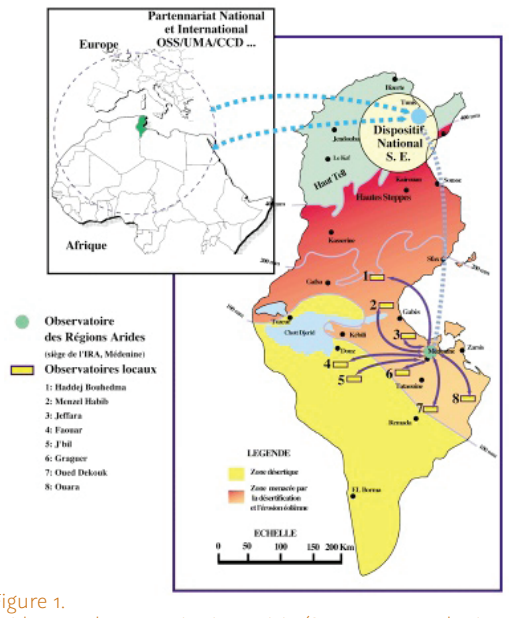

Figure 1.
Arid zone observatories in Tunisia (SUMAMAD study sites are found in 1 and 3) Source: Sghaier *et al.*, 2006

support countries to set up dashboards on combating desertification that serve the implementation of national policies for environment protection and the sustainable management of natural resources. This programme includes projects and initiatives for environmental monitoring at various levels and by various means: from small scale studies in the field to large scale studies using satellite images. It focuses on supporting the establishment of environmental monitoring mechanisms by countries to support decisions for sustainable development.

Tunisia has set up a number of observatories based on agro-ecological and socioeconomic zoning (Sghaier *et al*., 2006), which are scattered throughout the country. The two study sites (Zeuss-Koutine watershed and Bou Hedma National Park) are among the eight observatories of the arid zones of the country (Fig. 1).

1.2 Background of the study area

1.2.1 Zeuss-Koutine watershed

The watershed of Zeuss-Koutine (including Oum Zessar watershed and the northern part of the Dahar plateau) is situated in southeast Tunisia, northwest of the city of Médenine. In fact, it represents a transect that stretches from the Great Oriental Erg in the east and the Dahar plateau in the west, crosses the Matmata mountains between Béni Khédache and Toujane and the open Jeffara plain, then the saline depression (Sebkha) of Oum Zessar before ending in the Gulf of Gabès (Mediterranean sea). The study site covers an area of 897 km^2 and the approximate coordinates of the central point are 33°16'N and 10°08'E.

The study site is characterized by steppe vegetation in an arid climate. There are some wadi beds and watercourses with a distinct species composition. Total rainfall is low (100–240 mm) and highly irregular. Temperature differences are extreme between the seasons ranging from -3°C (winter) to a high of 48°C (in summer). It is estimated that approximately 25,000 people live on this site. Anthropogenic pressure has increased considerably since the 1960s leading to environmental degradation with reduced vegetation cover and poor eroded soils. Olive production and cereal cultivation, based mainly on water harvesting systems, represents the main agricultural activity in the area, but there is also traditional breeding of camels and small-stock, especially in the northern part of the Dahar plateau, which contributes to the livelihoods of the population. The household economy is based on a diversification of activities seen as an adaptation strategy to climate, market and risk mitigation. Migration is also an important economic activity, generating a substantial income.

The main stakeholders in the region are government agencies, especially the services of the Ministry of Agriculture who are responsible for all the agricultural development programmes in the area, as well as professional organizations (farmers union, livestock breeders association, and so on), civil society associations (NGOs), and research institutions (Arid Regions Institute [IRA], and l'Institut de l'Olivier) for specific scientific and technical backstopping.

1.2.2 Bou Hedma National Park

Bou Hedma National Park (34°39'N and 9°48'E) covers an area of approximately 16,488 ha and was designated as a UNESCO biosphere reserve in 1977. The park is divided into different zones: three Integral Protection Zones (IPZ) or core areas, two buffer zones (BZ), and two agricultural zones (AZ) or transition areas. The altitude varies between 90 m and 814 m above sea level.

The park is characterized by an arid Mediterranean bioclimate with a moderate winter (Le Houérou,

1959), with a mean annual rainfall of 180 mm, a mean annual temperature of 17.2°C, and a minimum and maximum monthly mean temperatures of 3.8°C (December and January) and 36.2°C (July and August), respectively.

The Bou Hedma soils are skeletal in the mountainous area, superficial and stony in the piedmont, and sandy to sandy-loamy in low-lying flat areas. On the mountainous massif, natural vegetation is dominated mainly by vestigial forest species such as *Juniperus phoenicea*, *Periploca angustifolia*, *Rhus tripartitum*, *Olea europaea*, *Rosmarinus officinalis* and *Stipa tenacissima*. *Artemisia herba-alba*, *Anarrhinum brevifolium*, *Gymnocarpos decander,* and *Helianthemum kahiricum* colonize the piedmont. The flat area is dominated by pseudo-savannah vegetation with *Acacia tortilis* subsp. *raddiana* as the only tree stratum. However, the understory stratum is dominated by many species such as *Rhanterium suaveolens*, *Cenchrus ciliaris*, *Haloxylon schmittianum*, *Haloxylon scoparium* and *Salvia aegyptiaca*.

It is estimated that approximately 15,000 people live in scattered dwellings in the vicinity of the park. They practice mainly arboriculture (fruit and olive trees) and cereal cultivation, using water harvesting structures (tabias) and small scale irrigation, and livestock breeding.

1.3 Main features and challenges of the study sites

In Tunisia, drought and desertification particularly affect the arid and semi-arid regions, which are characterized by unfavourable climatological and hydrological conditions. Low and erratic rainfall results in frequent periods of serious drought, alternating with flood periods and causing major damage and soil erosion (Floret and Pontanier, 1982). Over the past two decades, the Tunisian government has engaged in a vast programme for the conservation and mobilization of natural resources with national strategies for soil and water conservation, forest and rangelands rehabilitation, and water resources.

In the Jeffara, which encompasses one of the study sites (Zeuss-Koutine), the traditional production systems combine a concentration of means of production in limited areas with an extensive exploitation of pastoral resources in the major zone. However, during the last forty years, the rapid and remarkable evolution of these production systems together with natural resource exploitation has increased the exploitation of groundwater aquifers by drilling for the development of irrigated crops and industry. This is coupled with the rapid extension of fruit tree orchards at the expense of natural grazing lands, which followed the privatization of collective tribal lands. In this context, the spatial agrarian system momentarily disappeared and was replaced with other interconnected and adjacent production systems. Those systems are marked by competition for access to the natural resources, especially for land ownership and water use (Genin *et al.,* 2006). Huge efforts for soil and water conservation and rangelands rehabilitation have been implemented whose immediate effects are visible, but their efficiency in the short and long term has not yet been assessed and evaluated in detail.

In the framework of the national strategy for the preservation of natural ecosystems, numerous national parks have been set up to represent the main ecological zones of the country. The Bou Hedma National Park is considered one of the most important national parks in the country because it covers a pseudo-savannah-like ecosystem where the endangered *Acacia raddiana* can be found; a key tree species in the pre-Saharan zone that survives on the fringes of the desert. A number of studies has already been conducted in the fields of phenology and ecophysiology on the Acacia trees. However, the

dynamics of Acacia populations and their effect on the soil's physical and chemical properties have not been studied in detail.

In line with the UNCCD National Action Programme, in which desertification is considered a development issue, a search for alternative income-generating activities for the affected local population has become a priority so as to alleviate pressure on the natural vegetation, while reducing poverty.

Within this framework, the SUMAMAD objectives, as applied in the Tunisian research sites, are as follows:

TABLE 1.
AN OVERVIEW OF SUMAMAD ACTIVITIES AND OBJECTIVES

SUMAMAD activities	Objectives in Tunisia
Assessment of the current status of integration	Identify interactions between the evolution of resource utilization methods, production systems and land ownership.
Identification of practices for sustainable soil and water conservation	Assess and validate the various old and new practices for soil and water management and combating desertification.
Identification of training needs	Provide suitable training for the IRA team and its partners in the various themes within the project.
Identification of one to two income-generating activities	Identify alternative income-generating activities to improve the livelihood of the local population, while alleviating the pressure on natural resources.

2. Improved dryland agriculture and rehabilitation of degraded areas

2.1 Groundwater recharge by water harvesting techniques

In the framework of the implementation of the national strategy for soil conservation since 1990, numerous groundwater recharge structures (gabion check dams and recharge wells) (Fig. 2) have been installed to mobilize the runoff water for the replenishment of the underneath aquifers. Around ten recharge wells have also been installed to ensure the direct recharge of flood water retained behind gabion check dams to replenish the aquifers underneath. Previous studies (Yahyaoui & Ouessar, 2000; Ouessar, 2007) have shown that short-term effects are positive, but that the long-term impacts need to be investigated. The aim of this study is therefore to assess the performance of these structures. The work conducted in the watershed of wadi Hallouf (Médenine) involved the preparation of a field survey template and the implementation of surveys in the field. A total of 58 gabion recharge check dams were studied, which were constructed between 1993 and 1999 in the framework of the implementation of the national strategies for soil conservation and water resources mobilization.

The work conducted in the watershed of wadi Hallouf (Médenine) consisted of:

- Inventory and detailed characterization of the recharge wells.
- Collection of additional information: piezometric levels, gabion check dams characteristics and location, geological and hydro-geological settings, and so on.
- Analysis of the collected data.

A total of 10 recharge wells have been studied.

Figure 2.
Gabion check dam (right) and recharge well (left). © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

2.2 Dynamics and ecological impacts of Acacia plantations

2.2.1 Estimation of Acacia population and tree attributes

Forest ecosystems influence human well-being. About 30 per cent of the world's forests have groundcovers between 10 and 30 per cent. Although these forests are essential resources for millions of rural people in developing countries, they are badly and often under inventoried. Moreover, these open forests have special features that provide excellent opportunities for forest inventory using remote sensing. Hence, future trends in these forests are hard to predict (Ozdemir, 2008). The aim of this study is to perform a mono-temporal assessment of the amount of *Acacia raddiana* and their crown diameter classes in Bou Hedma National Park using high-resolution satellite images.

For satellite image processing, ground truth is required for the classification and calibration of empirical models to estimate the attributes of individual *Acacia raddiana* trees. In order to cover the different spatial arrangements of trees, a random sampling scheme was selected (Fig. 3). For each tree or tree group, different tree attributes were measured: bole diameter at the base and at breast height, total tree height, and crown diameter (Fig. 4). Stages of phenology (leaf, flower and fruit), soil stoniness, and erosion crust under and outside the tree canopy were visually determined using distinctive classes. Finally, vegetation under the tree canopy and outside the tree canopy was identified, together with the presence of animal faeces. Data were normalized and compiled in a relational database.

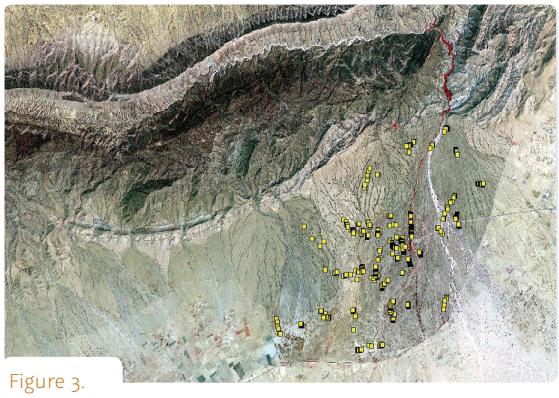

Figure 3.
Sampling scheme in Bou Hedma National Park.
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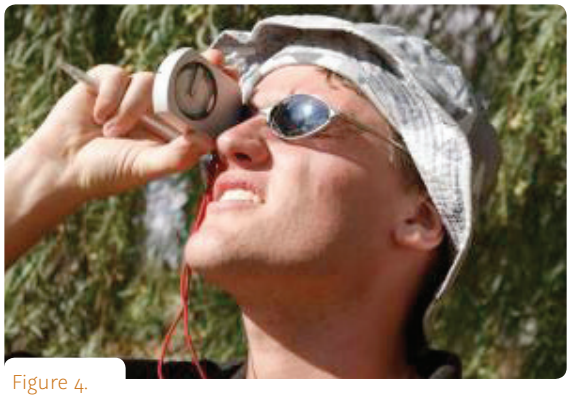

Figure 4.
Height determination of tree using a clinometer.
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2.2.2 Effects of reforestation on soil properties, near-surface water content and microclimate

The aim of this study is to quantify the effects of the Acacia plantation on chemical and physical soil properties, near-surface water content and microclimate. To enable the quantification of these effects, two sub-habitats were distinguished: tree-covered and open areas, and underneath and outside the canopy of Acacia trees, respectively (Fig. 5). Underneath the canopy, seven different sampling locations were selected: four along a transect to the north, and the remaining three in the other major wind directions (Fig. 6).

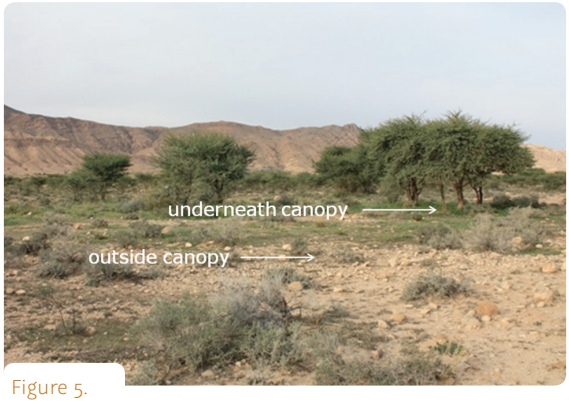

Figure 5.
Sub-habitats underneath and outside Acacia trees in Bou Hedma National Park. © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

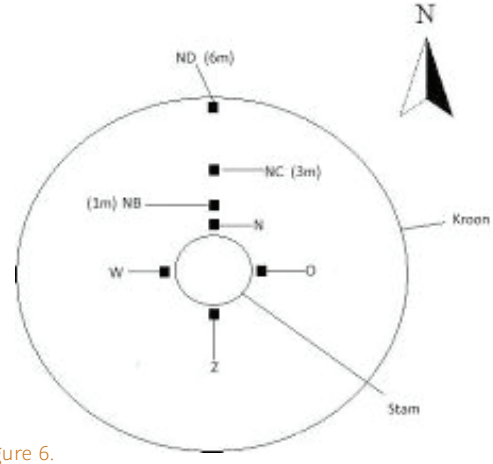

Figure 6.
Sampling scheme underneath an Acacia tree.
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Concerning the soil chemical properties, samples were taken of the top layer (0–10 cm) and analysed for pH, EC, %OM, %$CaCO_3$, Ca, K, Mg, Na and P. Concerning the soil's physical properties, infiltration measurements were undertaken underneath and outside the canopy with a tension disk infiltrometer to determine the unsaturated hydraulic conductivity at three different pressure heads (-3, -6 and -12 cm) and the derived saturated hydraulic conductivity (Fig. 7). In addition, undisturbed soil samples were taken (using a Kopecky ring) to determine the bulk density and the soil water retention curve. Beside the structural characterization of the soil, its texture was also determined.

To investigate the effect of the Acacia plantation on the near-surface water content (0–10 cm), a monitoring campaign, after an extreme rainfall event of 26.5 mm during autumn 2011, was executed using a TDR probe (Fig. 8). Measurements were taken underneath and outside the canopy, respectively at 0.5 and 10 m in the northern direction of each tree. To further investigate the soil water balance underneath (along a gradient) and outside the canopy of one tree, TDR sensors were installed at four different depths (5, 15, 25 and 40 cm) during autumn 2012 to automatically monitor soil water content over one year (Fig. 10).

Figure 7.
Infiltration measurements using a tension disk infiltrometer.
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Figure 8.
Trime-FM TDR (Eijkelkamp Agrisearch Equipment, Giesbeek). © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

In 2009, IRA installed a weather station in Bou Hedma National Park to automatically monitor some agro-meteorological parameters: temperature, rainfall, air temperature and humidity, wind velocity and direction, and global radiation (Fig. 9). To characterize the microclimate underneath and outside the canopy, and to link those measurements with the already installed weather station, measurements of the soil and air temperatures and humidity were done during autumn 2009 and 2011. In order to monitor those parameters automatically, a small weather station was installed under one tree during autumn 2012 (Fig. 10).

Figure 9.
Weather station inside Bou Hedma National Park installed by IRA. © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

Figure 10.
Installed weather station and TDR sensors under one tree inside National Park Bou Hedma © M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

3. Scenarios for future landuse changes

The impact analysis of land use changes on livelihoods was based on the Sustainable Livelihoods Framework (SLF), which has been applied with a group of households located at four different agro-ecological and socioeconomic zones or land use type (LUT) of the Wadi Hallouf/Oum Zessar watershed (Médenine) (Fig. 11).

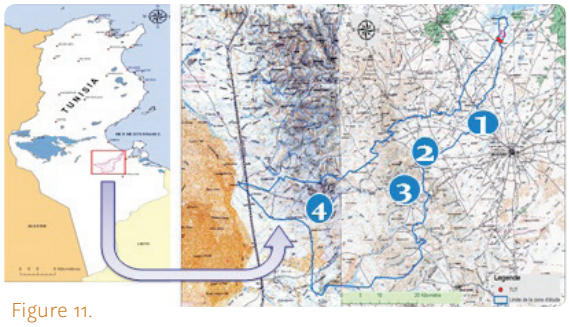

Figure 11.
Location of interviewed households by LUT
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TABLE 2.
LIST OF INDICATORS BY TYPE OF LIVELIHOOD CAPITAL

Physical capital	Natural capital	Human capital	Social capital	Financial capital
- Farm equipment - Mechanization - Transport	- Heads of livestock - Farm size (Land) - Land quality - Water quality - Rangeland quality	- Education - Household size - Number of workers - Know-how - Technical support	- Organizational affiliation - Access to land - Market Access - Access to health - Access to education - Access to safe water	- Subsidies - Farm income - Income from livestock - Off-farm income

A set of indicators given in Table 2 by type of livelihood assets was identified. These assets together enable people to pursue sustainable livelihoods.

4. Ensuring sustainable livelihoods through alternative income-generating activities

4.1 Aromatic and medicinal plants in the Matmatas (southeast region of Tunisia) as a source for alternative income generation[1]

The main aim of this activity is to combat natural resources degradation and improve the income of rural communities through rehabilitation, conservation and production diversification. For nearly a decade, aromatic and medicinal plants (AMP) in Tunisia have enjoyed renewed interest at the various departments, especially in agriculture, health, environment, industry, and scientific research. This sector is a means of diversifying agricultural production and the exploitation of fragile areas with limited economic potential. Thus, it can offer populations in fragile areas a relatively good source of income.

The overall objective is to increase and diversify sources of income for both women and men in the area through improved AMP productivity and market linkages. Two components have been addressed (Sghaier *et al*., 2011), as below.

Pilot development of the AMP value chain: this component aims to analyse the AMP value chain and to identify key constraints and entry points for smallholders in order to increase the value added retained at their level. The component will include the following activities:

- Assessing the AMP value chain in the areas of Médenine and Tataouine covered in this project. The assessment will result in the identification of constraints and opportunities for smallholders, traders and processors, as well as identification of collaborative initiatives between producers and processors. The result should also highlight activities that have the highest impact on women's economic empowerment.

1 This activity is carried out as part of a larger project, the Rehabilitation, Conservation and Promotion of Aromatic and Medicinal Plants (AMP) in the Matmatas (southeast region of Tunisia), coordinated by Prof M. Neffati (Rangeland Ecology Lab, IRA) and funded by ICARDA and IFAD.

- Based on the results of the assessment, the activity will pilot the development of market linkages between farmer groups, traders and processors. This implies the following: a) collaborating with local non-governmental organizations (NGOs) in the formation of farmer groups, while making sure that women are equally integrated in the groups; and b) the identification of traders and processors interested in piloting an improved AMP value chain.

Agricultural extension of the AMP production: this component aims to support farmer groups in the AMP quality production required by the market. This includes:

- Organizing training sessions for farmer groups and on-farm visits to members of these groups on AMP production, market standards, and the impact of quality change on sale price and producer margins. The sessions include practical training on complementary activities to AMP such as apiculture.

- Working with farmer groups to test and adapt the technical packages developed by IRA.

- Assisting farmer groups in the collection, conditioning and AMP seed production.

- Short technical briefs on market-oriented production of AMP, based on the results of the training and testing of technical packages produced by the project.

This part aims to describe and analyse the development work of an experimental value chain based on the mint species as an aromatic and medicinal plant. Mint has been identified at the first stage of the Arid Regions Institute (IRA) – International Center for Agricultural Research in the Dry Areas (ICARDA) – International Fund for Agricultural Development (IFAD) project as one of the priority target species for the project. Indeed, the study of the sector of the main aromatic and medicinal plants species has been utilized to implement the pilot dried mint project in the governorates of Tataouine and Médenine.

The choice and selection of this species were made following a consultation process with local stakeholders through planning workshops. These workshops were held in El Smar and Ghordhab (Tataouine Governorate) with the participation of researchers from the IRA, PRODESUD project staff, representatives of the Groupement de Développement Agricole (GDA)[2] of El Smar Farech, and a set of traders and farmers interested in AMP.

The main steps and activities in the implementation of the experimental value chain of mint can be summarized as follows (Fig. 12):

- Planning meeting with the GDA of Smar and El Ferch and farmers.
- Identification of producers (mainly women) in both regions.
- Plot installation for producers.
- Crop management.
- Harvesting and marketing the first fresh product at the local market.
- Training on techniques for drying and conditioning.
- Harvest products for packaging.
- Traditional drying.
- Drying and packaging industry (in Perfect Food, Médenine).
- Packaging design and prototyping.
- Production of packaging.
- Placing the goods in packaging.
- Supervision of merchant partners (upgrade).
- Distribution and sale of products to consumers.

2 Agricultural Development Group.

Figure 12.
Illustration of the main steps of the installation of the mint sector in the governorate of Tataouine.
© Mongi Sghaier (IRA, Médenine)

4.2 Solidarity tourism: a source for alternative income of rural families in the drylands of Tunisia[3]

Equitable (justice) and solidarity tourism is defined by tourism values that place the human being at the heart of the journey, and which are a clear indication of a will to develop territories. The involvement of local populations in the different phases of the project, respecting human beings, their culture, nature, and a more equitable distribution of all resources generated are the basis of this type of tourism.

It is under this umbrella that a group of NGOs[4] in southeast Tunisia are working together to develop a network for solidarity tourism in the region. SUMAMAD co-financed two workshops devoted to training members of the NGOs on the development of projects and activities in this field.

Figure 13.
First workshop (May 2011).
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Figure 14.
Second workshop (November 2011).
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3 This work was mainly conducted by: R. Jaafar, A. Hamrouni, M. Ouessar and M. Sghaier.

4 AJZ: Association de Jeunes de Zammour (Médenine); ASOC: Association de Sauvegarde de l'Oasis de Chénini, Gabès; ASNAPED: Association de Sauvegarde de la Nature et de Protection de l'Environnent à Douiret, Tataouine.

Meanwhile a specific programme has been launched between AJZ and Tamadi Voyage5 – a travel agency based in France and Belgium specializing in this type of tourism.

5. Results obtained

5.1 Groundwater recharge structures

The rate of silting up the structures is very high and decreases from upstream (90%), middle stream (88%) to downstream (81%). Exceptional rainfall events could wash up large numbers of those structures: 51% of the structures are in very bad condition and 40% are in average condition after heavy floods.

Out of the 10 already installed recharge wells, only three of them are functioning properly. The major causes are: underestimation of the required depth to reach the groundwater or permeable layer, use of inappropriate drilling machinery that encounter difficulties in digging through the very hard layers, and unexpected geological settings (faults, geological layer) because of the absence of geophysical surveys.

5.2 Acacia plantations

5.2.1 Vegetation dynamics and tree attributes

Geographic Object-Based Image Analysis (GEOBIA) can correctly delineate trees with both small and large crown diameters. The distribution of crown diameters shows a clear presence of trees with diameters between 3 and 5 m. An exponential decrease is present for trees with larger crown diameters. Trees with smaller crown diameters seem to be less present. This is in accordance with field observations, however it is probable that smaller trees are not all detected by segmentation or classification algorithms, especially for crown diameters at 0–2 m. Moreover, this structure is highly influenced by reforestation actions, which were undertaken in 1963, 1966/1967, 1995/1996 and 2001 (Lazhar Hamdi, personal communication). Results indicate an uneven-aged forest structure, with a lack of small individuals. Reasons for the lack of small individuals are limited natural regeneration and no visual detection of small individuals during image processing.

Analysis of erosion crust classes revealed a higher erosion crust cover outside than under the tree canopy, indicating soil protection by tree cover. Stoniness classes were consistent with field observations with a gradient from the mountain towards the sandy plain.

Based on the presence of animal faeces, a clear preference for grazing by herbivorous fauna (*Oryx sp.*, *Addax sp.* and *Gazella sp.*) was found near larger trees. This is mainly driven by the amount of shade provided by larger trees.

Empirical equations to estimate individual *Acacia raddiana* tree attributes (bole diameter, stem volume and tree height) were modeled and performed with acceptable root-mean-square error (RMSE) values.

Density was determined by counting the number of Acacia trees (both groups and individuals) per ha. A mean density of 8.4 trees per ha was found, in line with the historical density of trees in Bou Hedma National Park (4 to 25 trees/ha).

5.2.2 Soil properties and microclimate

Significant differences were found in soil chemical properties, but there was no real consistency between them. A trend of decreasing values was

5 www.Tamadi.org

observed when moving away from the stem in the transect to the north, and this for all the parameters. In comparison with a previous study in the same area executed during the growing season of 2003–2004 (Abdallah *et al.*, 2008), a general improvement of the chemical quality of the soil can be noticed, especially the organic matter content and this outside of the canopy. These findings suggest that the positive effects of Acacia plantations are already extended to the open area.

Soil and air temperature were much lower underneath than outside of the canopy, especially during the hot summer months. The trees have a buffering effect on the microclimate, and extreme conditions are avoided. Higher relative air humidity was observed under the canopy than outside the canopy. The relationship between the meteorological parameters underneath and outside the canopy and their effect on the soil water balance will be further investigated.

Clear differences were found in the soil hydraulic properties and soil water retention underneath and outside the canopy of Acacia trees. Acacia plantations have a positive effect on the initial water content due to enhanced infiltration, and the related water retention capacity of the upper soil layer due to the improved soil structure. Moreover, Acacia trees can ameliorate the transpiration and productivity of the ground cover vegetation by favouring the climatic conditions underneath and in the direct neighbourhood of their canopies (see Annex for poster of De Boever *et al.* (2012), presented at the Eurosoil 2012 conference).

5.3 Scenario for future landuses

In Figure 15, we show how these livelihood capitals have changed or shifted in the four locations during 2000 and 2010. It was noted that the natural capital has significantly decreased for most of the households in location 1 with very little increment in financial capital. Conversely, the financial capital of households in location 3 has increased due to income from off-farm employment, although the natural capital has declined. The human, social and natural capitals of households in location 2 have all decreased, but interestingly the financial capital has remained unchanged. Location 4, in the rangelands, appears to perform well with notable increases in human, physical and financial capitals and a very small decline in natural capital, indicating that the agro-pastoral system remains a viable livelihood with limited negative impact on the natural resource base, especially if the system is well managed. Ultimately, the consequences to livelihoods vary depending on the local environment and its socioeconomic conditions.

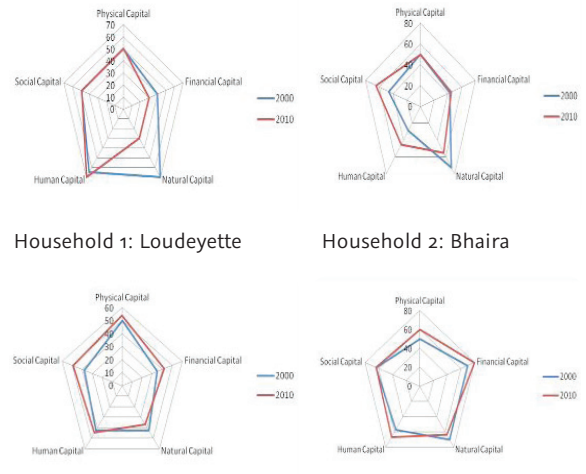

Figure 15.
Differences in livelihood structure during 2000 and 2010.
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The livelihood trends in terms of five capital assets are presented in Figure 16. Indeed, social capital increases rapidly compared to human, physical and

financial capitals at the expense of the natural capital, which shows a downward trend due to intensification, over-extraction and poor management.

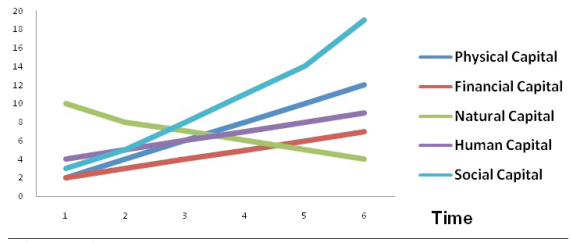

Figure 16.
Trends of different livelihood capitals over time.
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To conclude, land use is distinctively marked as either rangeland or cropland. Land use change was primarily driven by the land privatization policy and population growth. The pattern of land use change was linear, that is, from rangelands to agro-pastoral and croplands, although variability within these land uses is quite high. Land privatization triggered sedentary agro-pastoral systems, agricultural expansion in rangelands, and the intensification of crop and livestock system, which opened up opportunities for agriculture development, pushing farmers to graze and farm in marginal areas. However, optimal production is basically at odds with low and irregular rainfall, hence, the expansion of irrigated perimeters continues through the exploitation of surface and deep groundwater aquifers, running the risk of over-exploitation and the depletion of this very important resource.

Furthermore, the process of land degradation continues through soil, water and wind erosion, despite efforts to mitigate them. Biodiversity loss has been also observed with the conversion of native rangelands into agriculture. The consequence to livelihoods has been ambivalent. The livelihoods analysis has shown that social capital has increased more rapidly than human, physical and financial capitals at the expense of the natural capital. This could mean that building social capital has seen the greatest impact of past and ongoing interventions. Furthermore, the livelihood analysis also suggest that increases in financial capital is only marginal, even if the natural resources were to be depleted this will become more serious if the status quo is left unchallenged. Among the many land management options, the jessour and tabias, spillway and resting techniques were commonly preferred, while plantation and contour stone ridges were rated low.

5.4 Alternative income generation

5.4.1 Mint value chain

The approach channel aimed primarily at poor families and rural women (52 women). It allowed the mobilization of various socio-professional categories (farmers, mostly women, GDA, traders, industrialists, and so on). The value chain approach has increased the profit margin of mint (200 to 800%) and created new sources of income for families and rural women. It has also trigged the establishment of local dynamics based on partnership between actors (farmers, GDA, CRDA, IRA, and so on).

The sector has also developed synergies between partners, stakeholders and the local population (IRA, ICARDA, CRDA, PRODESUD, GDA, women, men, UTAP FIU authorities, and so on).

The sale of dried mint allows different operators (GDA, herbalists and intermediate traders) to obtain a higher profit margin than for the sale of fresh mint. More operations in the sector developed processes for packaging and processing, plus the industry generated a higher gross margin without touching or reducing the share of producers, who maintain their profit margins at a satisfactory level.

5.4.2 Solidarity tourism

The project contributed towards the capacity building of some members of the main NGOs operating in the region (southeast Tunisia) in the domain of solidarity tourism as a form of alternative income generation for the local population. In the mountain region of Beni Khedache (province of Médenine), the NGO of AJZ, which is an active collaborating partner of IRA, succeeded in integrating their intervention area (Zammour) in one of the official circuits of one of the more reputed international travel agencies specializing in solidarity tourism (Fig. 17).

6. Recommendations for sustainable drylands management

6.1 Natural resources management

- Reconsidering the main roles assigned to groundwater recharge structures so as to increase their efficiency.
- Many factors need to be considered for the selection of the recharge well sites. The approach applied represents one of the approaches to be followed.
- Reforestation of degraded drylands is possible and has major beneficial environmental impacts on ecosystem services.

6.2 Policy decision-making system

The situation in the study area indeed requires an integrated natural resources management (NRM) approach that is embedded in the broader context of rural development. Participatory integrated NRM however, requires a shared understanding of what multiple stakeholders expect to get out of the watershed, as a basis for broader collective action with local, regional and central government actors. The use of participatory tools could contribute substantially to:

- Mutual learning among local and external actors by sharing experience and jointly reflecting on current and potential problems and potential management options.

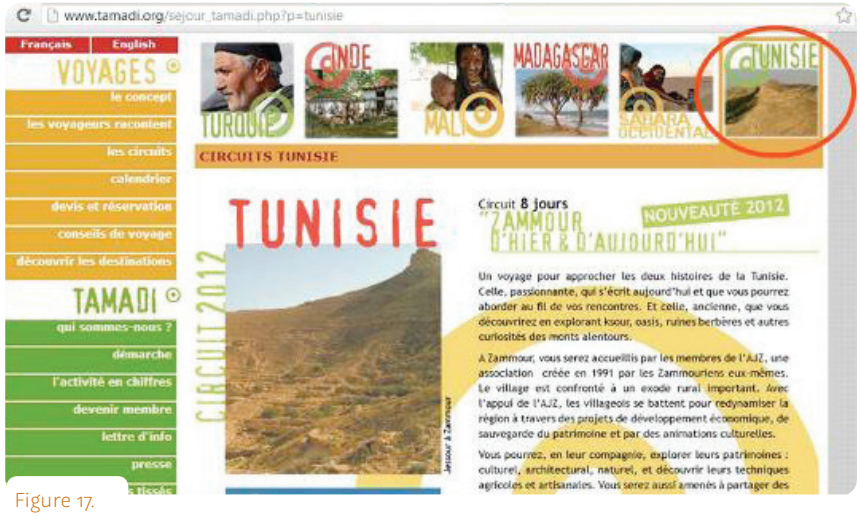

Figure 17.
The Zammour circuit is now officially endorsed by the Tamadi network.
© M. Ouessar, M. Sghaier, M. De Boever, D. Gabriels

- Create a common understanding of problems, potentials and opportunities by integrating external and internal perceptions.
- Strengthen trust and collaboration among concerned stakeholders.
- Identify existing and new NRM technologies.

6.3 Income generation

- Small scale projects could be launched based on the aromatic and medicinal plants in order to provide employment and/or alternative income-generation activities.
- Better organization of the marketing channels can assist in promoting MAP programmes.
- Encourage solidarity tourism to expand in the region.

7. Research institution and team composition

Partner institution
Institut des régions arides (IRA)
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Team leader
Mohamed Ouessar
Water harvesting
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Mondher Fetoui
Geography
Institut des régions arides

Azaiez Ouled Belgacem
Rangeland ecology
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Ghent University, Belgium

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Remote sensing
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Wim Cornelis
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Ghent University, Belgium

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Hydrogeology
Commissariat Regional au Développement Agricole de Médenine (Regional department of the Ministry of Agriculture) (CRDA)

Lazhar Hamdi
Biodiversity
Bou Hedma National Park (BHNP)

NGO sub-team
Rachid Jaafer
Association des Jeunes de Zammour à Béni Khédache (Youth Association of Zammour in Beni Khédache) (AJZ)

8. List of national seminars

In addition to the various informal meetings and exchanges, seminars and workshops have been organized to which national partners and local authorities were invited to attend.

TABLE 3.
LIST OF NATIONAL SEMINARS

Date	Participants	Organizations	Main Outcomes/ recommendations
11/11/2009	17 (10 M; 7 F)	CRDA, ODS, NGOs	First hands on the project's phase II: Background, objectives main expected results.
10/06/2010	22 (14M, 8F)	CRDA, ODS, OEP, UTAP, NGOs	Better integration of research actions in development programmes. Specific attention to be given to climate change impacts and adaptation.
17/06/2011	20 (15M, 5F)	CRDA, NGOs, OEP, Gov.	Evaluation of government efforts/ programs.
06/09/2012 04/12/2012	24 (18M, 6F) 14 (12M, 2F)	CRDA, NGOs, OEP, ODS, Gov.	Mainstreaming of risks and changes Develop strategic planning program

9. Publications as a result of SUMAMAD

De Sadeleer, K. 2010. Influence of afforestation on soil properties and microclimate in Bou-Hedma National Park in semi-arid Tunisia. MSc thesis, University of Gent, Belgium.

Delaplace, K. 2010. Monotemporal assessment of amount of Acacia's (individuals, tree groups) and estimation of crown diameter classes of *Acacia raddiana* in Bou-Hedma National Park, Tunisia. MSc thesis, University of Gent, Belgium.

Delaplace, K., F. Van Coillie, R. De Wulf, D. Gabriels, K. De Smet, M. Ouessar, A. Ouled Belgacem, H. Taamallah. 2010. Object-based assessment of tree attributes of *Acacia tortilis* in Bou-Hedma, Tunisia. Poster presented at the GEOBIA 2010 Conference, June 29–July 2, 2010. Ghent, Belgium.

Delaplace, K., F. Van Coillie, R. De Wulf, D. Gabriels, K. De Smet, M. Ouessar, A. Ouled Belgacem, H. Taamallah. 2010. Object-based assessment of tree attributes of *Acacia tortilis* in Bou-Hedma, Tunisia. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVIII-4/C7.

Ouessar, M., D. Gabriels, H. Yahyaoui, S. Temmerman. 2012. Laboratory simulation of the efficiency of groundwater recharge well filters. International Centre for Theoretical Physics, Trieste.

Ouled Belgacem, A., M. Tarhouni, M. Louhaichi. 2011. *Effect of protection on plant community dynamics in the Mediterranean arid zone of southern Tunisia: a case study from Bou Hedma national park*. Land Degradation & Development (published online in Wiley online library (www.wileyonlinelibrary.com) doi: 10.1002/ldr.1103).

10. References

Abdallah, F., Noumi, Z., Touzard, B., Ouled Belgacem, A., Neffati, M. & Chaieb, M. 2008. The influence of *Acacia tortilis* (Forssk.) Subsp. *Raddiana* (Savi) and livestock grazing on grass species composition, yield and soil nutrients in arid environments of South Tunisia. *Flora*, Vol. 203, pp. 116-125.

Floret, C., Pontanier, R. 1982. *L'aridité en Tunisie présaharienne: Climat, sol, végétation et aménagement*. ORSTOM, Paris.

Genin, D., Guillaume, H., Ouessar, M., Ouled Belgacem, A., Romagny, B., Sghaier, M., Taamallah, H. (eds). 2006. *Entre la désertification et le développement: la Jeffara tunisienne*. CERES, Tunis, p. 351.

Le Houérou, H.N. 1959. *Recherches écologiques et floristiques sur la végétation de la Tunisie méridionale*. Institut de Recherches Sahariennes de l'Université d'Alger, Alger, p. 520.

MEAT (Ministère de l'Environnement et de l'Aménagement du Territoire). 1998. *Plan d'action national de lutte contre la désertification*. MEAT, Tunis.

Min. Agr. (Ministère de l'Agriculture). 1990*a*. *La stratégie nationale de la conservation des eaux et du sol (1991–2000)*. Ministère de l'Agriculture, Tunis, Tunisia, p. 29.

Min. Agr. (Ministère de l'Agriculture). 1990*b*. *La stratégie nationale des ressources en eau 1991–2000)*. Ministère de l'Agriculture, Tunis, p. 35.

Min. Agr. (Ministère de l'Agriculture). 2002. *Carte agricole de la Tunisie*. Ministère de l'Agriculture, SCOT/STUDI/SODETEG, Tunis.

Ouessar, M. 2007. Hydrological impacts of rainwater harvesting in wadi Oum Zessar watershed (Southern Tunisia). Ph.D. thesis, Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium, p. 154.

Ozdemir, I. 2008. Estimating stem volume by tree crown area and tree shadow area extracted from pan-sharpened Quickbird imagery in open Crimean juniper forests. *International Journal of Remote Sensing*, Vol. 29, pp. 5643–5655.

Sghaier, M., M. Jaouad, A. Tbib, M. Fetoui, M. A. Ben Abed, M. Louhichi, N. Saidi, N. Ounalli, K. Khadkhadi. 2006. *Surveillance socio-économique, pratiques et usages des ressources naturelles dans l'Observatoire de Menzel Habib*. ROSELT/OSS.

Yahyaoui, H., M. Ouessar. 2000. Abstraction and recharge impacts on the groundwater in the arid regions of Tunisia: Case of Zeuss-Koutine water table. In: Proceedings of the international workshop on Water management in dry areas, Médenine, Tunisia; 18-22 October 1999, *UNU Desertification Series*, N°2, 72-78.

11. Annex

Influence of Acacia plantations on the soil water content in arid zones of Tunisia

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Background

- important role of trees in arid regions
  - reduction of negative effects of soil aridity and climate (Anderson et al., 2001)
  - strong influence on the environments under their canopy (Belsky and Canham, 1994)
  - effective measure against soil erosion and desertification (Young, 1989)
- *Acacia raddiana*
  - keystone species persisting on the edge of the desert
  - important woody species in pre-Saharan Tunisia
  - able to resist extreme droughts

Objective

To investigate the impact of an *Acacia raddiana* plantation on the near-surface soil water balance and more specific on the water content and the water-holding capacity of the soil

Study area

Fig. 1. Geographical location of National Park Bou-Hedma (Tarhouni et al., 2007)

- National Park Bou-Hedma (Fig. 1 & 2)
  - location: central Tunisia
  - total surface: 5.115 ha
  - pseudo-savanna ecosystem
  - climate:
    - arid with moderate winter
    - annual rainfall of 180 mm
    - rainfall season from Sept. till Dec.
  - since 1950: different afforestation programmes with *Acacia raddiana*
- 3 study locations:
  - two sub-habitats inside National Park Bou-Hedma (Fig. 3):
    - underneath canopy Acacia
    - outside canopy Acacia
  - outside National Park Bou-Hedma (Fig. 2)

Fig. 2. Inside (white border) and outside National Park Bou-Hedma (zone between white and red border)

Fig. 3. Inside National Park Bou-Hedma with sub-habitats underneath and outside the canopy of Acacia

Methodology

Soil water content

- monitored for 21 days
- after extreme rainfall event of 25.6 mm
- upper soil layer (0-10cm)
- simultaneously inside (underneath and outside canopy) and outside the park
- using TRIME-FM TDR (Time Domain Reflectometry) with 3 rods of 12 cm (Fig. 4)

Fig. 4. Trime-FM TDR (Eijkelkamp Agrisearch Equipment, Giesbeek)

Soil water retention curve

- soil water retention curve (SWRC) relates the pressure head to the water content of the soil
- used to determine the soil water-holding capacity, i.e. the water content between field capacity (F.C.) and permanent wilting point (P.W.P.)
- Sandbox apparatus (Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands) was used to determine SWRC points at high pressure heads
- Pressure plate apparatus (Soil Moisture Equipment, Santa Barbara, CA) was used to determine SWRC points at low pressure heads

Results

- soil water content
  - highest underneath the canopy, second highest outside the canopy and lowest outside the park one day after the rainfall event (d1) (Table 1)
  - inside the park, the decline in water content was similar underneath and outside the canopy during the first week (d1-d8) (Fig. 5)
  - during the second and third week (d8-d21), the decline in water content was more than twice larger underneath than outside the canopy
  - outside the park, the decline in water content was limited
- water-holding capacity
  - significantly higher ($p<0.05$) underneath than outside the canopy: 0.27 ± 0.04 vs. 0.22 ± 0.02 $m^3\ m^{-3}$ (Fig. 6)

Table 1. Mean and standard deviation (SD) for soil water content inside (under and outside canopy) and outside park

($m^3\ m^{-3}$)	under canopy	outside canopy	outside park
θ(d1)	0.30 ± 0.03	0.25 ± 0.04	0.14 ± 0.01
θ(d21)	0.08 ± 0.01	0.07 ± 0.01	0.04 ± 0.01
θ(d1-d8)	0.14	0.14	0.07
θ(d8-d21)	0.09	0.04	0.03

Table 2. Mean and standard deviation for organic matter content (O.M.) and soil texture inside (under and outside canopy) and outside park

	under canopy	outside canopy	outside park
O.M. (%)	2.32 ± 1.04	0.72 ± 0.11	0.60 ± 0.08
Soil texture	Sandy Loam	Sandy Loam	Sand
clay (%)	4.1	6.0	-
silt (%)	29.8	28.0	-
sand (%)	66.1	66.0	-

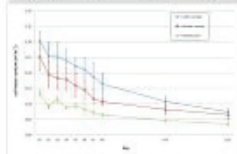

Fig. 5. Change of mean soil water content (with error bars for SD) for 21 days after rainfall event under and outside canopy (inside park) and outside park

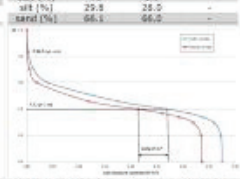

Fig. 6. pF curve under and outside canopy inside park with indication of difference in field capacity (F.C.) and similarity in permanent wilting point (P.W.P.)

Discussion

- difference in initial soil water content underneath and outside the canopy (Fig. 5) can be related to their difference in water-holding capacity of 0.05 $m^3\ m^{-3}$ (Fig. 6) and the latter will be affected by organic matter content but not by texture (Table 2)
- higher evapotranspiration underneath compared to outside the canopy starting from the second week (Fig. 5)
- as evaporation will be reduced underneath the canopy due to shading, the decline in water content can mainly be addressed to increased transpiration of the ground cover vegetation
- low initial soil water content outside the park can be explained by the combined effect of rapid evaporation of the water before entering the soil, sandy soil texture and low organic matter content (Table 2)

Conclusions

- positive effect of the Acacia plantation on the initial water content and the related water-holding capacity of the upper soil layer can be clearly noticed
- Acacia trees can enhance the transpiration and productivity of the ground cover vegetation by favoring the climatic conditions underneath and in the direct neighborhood of their canopies

Future research

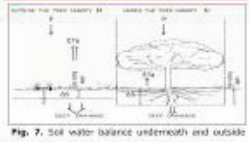

Fig. 7. Soil water balance underneath and outside canopy (modified from Joffre and Rambal, 1993)

- impact of Acacia plantation
  - on the soil water balance and related ecosystem services
    - $\Delta S = P - (R) - ETa - D$ (Fig. 7, with ΔS: change in soil water content, P: precipitation, R: runoff, ETa: actual evapotranspiration and D: drainage)
  - estimation of ETa underneath and outside canopy

References

Anderson, L.J., Brumbaugh, M.S. and Jackson, R.B., 2001. Water and tree-understorey interactions: a natural experiment in a savanna with oak wilt. Ecology 82: 33-49.
Belsky, A. J., and Canham, C. D., 1994. Gaps, patches, and isolated trees: a comparison of the patch dynamics of forest gaps and savanna trees. BioScience 44: 77-84.
Joffre, R., and Rambal, S., 1993. How tree cover influences the water balance of mediterranean rangelands. Ecology 74: 570-582.
Tarhouni, M., Ouled Belgacem, A., Neffati, M. and Chaieb, M., 2007. Dynamique des groupements végétaux dans une aire protégée de Tunisie méridionale. Cahiers Agriculture 16 (1): 7.
Young, A., 1989. Agroforestry for soil conservation. International Centre for Research in Agroforestry, ICRAF, Nairobi, Kenya.

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SUMAMAD

This publication synthesizes the results of the second phase of the Sustainable Management of Marginal Drylands project funded by the Flemish Government of Belgium. Scientists from ten countries – Belgium, Bolivia, Burkina Faso, China, Egypt, India, the Islamic Republic of Iran, Jordan, Pakistan and Tunisia – studied dryland ecosystems from a research, environmental conservation and sustainable development perspective. Their objective was to elaborate wise dryland management practices by involving local communities while satisfying their needs for sustainable livelihoods. Studied sites included field research stations and biosphere reserves, which also served as testing grounds for alternative income opportunities among dryland communities based on their perceived needs and priorities. It is hoped that the knowledge gleaned from the individual project sites will also benefit dryland regions in other parts of the world

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