Ecorestoration of Banni Grassland

First Annual Technical Report

Published by
Gujarat Ecology Commission
GERI Campus, Race Course Road, Vadodara - 390 007. INDIA

December, 1998

Ecorestoration of Banni Grassland

First Annual Technical Report

PROJECT TEAM

PROJECT COORDINATOR
Prof. Y. D. Singh

PRINCIPAL INVESTIGATOR
Dr. V. Vijay Kumar

RESEARCH BIOLOGISTS

Ishwar Lal Patel
Yogesh K. Sharma
Suresh V. Dangar
Dr. S.V. Subba Rao

Gujarat Institute of Desert Ecology

PATWADI NAKA BHUJ, KACHCHH, GUJARAT, 370 001, INDIA

December, 1998

PREFACE

Banni, a vast stretch of 3847 Km^2 area, located along the northern border of Kachchh district of Gujarat state supports a good number of livestock from Kachchh and other districts of the state and also neighbouring states like Maharashtra and Rajasthan. Today this area is severely degraded due to increasing salinity, overgrazing, climatic abnormalities and alarming invasion of *Prosopis juliflora.* This situation is evident from the fact that the human and livestock population of the area decreased by 25 and 47 per cent respectively.

To over come the existing issues, many developmental projects have been implemented in the area with a view to improve the socio-economic conditions of the people. However, results were not very satisfactory, because these efforts did not ensure the involvement of people and had ignored the ecological fragility of the region. Gujarat Ecology Commission (GEC), therefore, decided to make a novel and eco-friendly intervention to improve the living standards of Banni people under the Border Area Development Programme (BADP) of the Government of Gujarat.

GEC, after a series of interactions with the Banni people, laid out the plan for the development of Banni, while the implementation of that plan was carried out through Gujarat Institute of Desert Ecology (GUIDE) and Vivekananda Research and Training Institute (VRTI). Though the project activities commenced since late 1995, due to severe drought in 1995 and 1996, the actual results of the restoration work were visualised only in 1997. The present report deals with the one year recovery of the restoration sites located at Bhirandiyara and Dhordo and the comparative productive status of unprotected and *Prosopis juliflora* infested grassland areas of Banni. It also describes the pilot restoration activities carried at Bhirandiyara (reclamation of saline land by GUIDE) and Dhordo (development of degraded land by VRTI) villages of Banni to demonstrate the ways to improve the saline and degraded lands. The restoration activities are in progress, however, the results obtained after the 1997 monsoon is summarised in the present report. The results of the study enhance our hope of improving such areas. I hope the present report will help the researchers, planners and development agencies to understand the effects of proper management in puts on the development of degraded and saline lands.

Y.D.Singh

Director

ACKNOWLEDGEMENT

The Gujarat Institute of Desert Ecology, Bhuj, has prepared this First Annual Technical Report on the "Ecorestoration of Banni grassland" under the guidance of the Chairman and other Officials of the Gujarat Ecology Commission, Vadodara.

We are grateful to the officials of the Animal Husbandry Department of the Gujarat Government for the entire study support.

The present study has been made possible through the valuable help and co-operation of officials from Vivekananda Research and Training Institute - Mandvi, Banni Development Agency - Bhuj, Gujarat State Forest Development Corporation - Bhuj and local Banni villagers from Dhordo and Bhirandiyara.

We acknowledge with gratitude help extended by Mr. A. B. Lowelakar, Former Director of GEC and Mr. H.L.Lalka, Former Project Co-ordinator, Banni Restoration Project for providing various supports and suggestions.

We appreciate the help given by the Scientists and Staffs of GUIDE, with special referance to Dr. Justus Joshua and Dr. G. A. Thivakaran for editing the manuscript. Dr. A. M. Dixit for planning the methods, Miss Rashmi Dinesan for helping in analytical work and Mr. S.F.Wesley Sunderraj for taking photographs.

We also appreciate the secretarial assistance provided by Mr. N.K. Maheswari.

Project Team
Gujarat Institute of Desert Ecology

CONTENTS

LIST OF TABLES

S N **Title**

LIST OF FIGURES

EXECUTIVE SUMMARY

Gujarat Ecology Commission, a body set up by the Forest and Environment Department of Government of Gujarat initiated the Restoration programme in Banni during the year 1995 to enhance the sustainability of the degraded and saline area and thereby improve the socio-economic status of the local inhabitants, whose livelihood entirely depends on the livestock based economy. The implementation of the restoration programme was carried out through Gujarat Institute of Desert Ecology (GUIDE), Bhuj and Vivekananda Research and Training Institute (VRTI), Mandvi, while at the commencement of the programme, Gujarat Forest Development Corporation (GFDC), Bhuj helped in the eradication of *Prosopis juliflora* in the restoration sites. In the current project, the approach ofGEC was entirely different from earlier interventions under taken in the Banni by various agencies. As a first measure of this programme, GEC has identified and critically analysed the existing problems of Banni area through GUIDE, and based on which a work plan was designed to nullify the deteriorating factors. Further, GEC tried to involve people's participation in all the stages of its restoration activities.

Banni restoration was initially aimed to cover an area of 500 ha at 5 different sites. Latter on it was planned to extend the area in successive years. However, the administrative and local issues made it possible to initiate the programme only at two sites; 15 ha of high saline area at Bhirandiyara and 200 ha of degraded area at Dhordo. The implementing agencies have taken steps to hasten up the process of recovery of the saline and degraded areas since natural recovery of a degraded site is a slow process. The activities undertaken include; protection from grazing by a trench and or barbed wire fencing, removal of weeds *(Prosopis juliflora)* to reduce the competition, soil working such as shallow ploughing, slope making etc., farmyard manure application to improve the soil characteristics and reseeding to improve the seed bank of the sites. Though the activities commenced during the early 1996, the severe consecutive droughts which, prevailed during 1996 made it possible to see the recovery of the restoration sites only after 1997 monsoon, during which period Banni received over 700 mm rainfall.

The GEC's restoration activities are successful and is seen through the improvement of grass cover, species diversity and biomass of the restoration sites, which are far higher than the unprotected and *Prosopis juliflora* infested areas. Total 25 species belonging to 20 genus were recorded at Dhordo restoration site, which in turn decreased to 18 species in unprotected and 17 species in *Prosopis juliflora* infested areas of Dhordo. In the high saline area of Bhirandiyara, 12 species were recorded in the restoration site whereas it decreased to 6 species in the unprotected area located adjacent to it. Looking at the distribution, all the species recorded in the *Prosopis juliflora* area showed only aggregation while random to uniform distribution of certain species was recorded in restoration and unprotected areas at Bhirandiyara and Dhordo. This clearly highlights that *Prosopis juliflora* inhibits the growth of grass species under its canopy. Among the species, *Sporobolus helvolus* forms the dominant in both the ploughed and unploughed area of the Dhordo restoration site while *Cyperus rotundus* was dominant in unprotected and *Prosopis juliflora* infested area of Dhordo. *Cyperus haspan* was dominant in all the amendments of Bhirandiyara restoration site and unprotected area except on the narrow vertical slopes where *Aeluropus logopoides* was the dominant species.

In Dhordo, the biomass increased by 73 per cent in the restoration site and 18 per cent in the *Prosopis juliflora* infested area while it decreased to 32 per cent in the unprotected area. Similarly, in Bhirandiyara, the biomass increased to 100 per cent in the restoration site while it decreased to 32 per cent in the unprotected area. The decrease in biomass, especially of palatable species registered a high grazing pressure in unprotected areas. Interestingly, the biomass of the unploughed area was slightly higher than the ploughed area of both the restoration sites and it may be due to the germination of existing tillers and rhizome in the unploughed area while the same was disturbed in ploughed area and the germination occurred through the seeds sown in that area. This made slight decrease of biomass in the ploughed area in the initial stage (1997) and the situation may change in the successive years. It was also noted that, soil salinity plays a major role in governing the distribution of the grass species in an area. The productivity of species like *Cyperus rotundus, Eragrostis* sp., *Cressa cretica, Aeluropus logopoides* was not much affected by salinity, however their distribution was mostly restricted within 1.5 EC level. The productivity of species like *Sporobolus helvolus, Dichanthium annulatum* and *Cenchrus* sp. has decreased with increasing salinity. An interesting observation noted in the Bhirandiyara restoration site was that, the surface soil salinity reduced from 13 EC which was recorded before the initiation of the programme to less than 4 EC as on today. At Dhordo restoration site, total 1,75,100 kg grass fodder was harvested in December 1998 for the distribution to the local villagers, while harvesting was not undertaken at Bhirandiyara with a view to improve the soil organic matter. The increased grass cover of this area curtailed the soil water evaporation to a greater extent and thereby reduced salinity of the area. This situation further improved the soil condition of Bhirandiyara restoration site and thereby made it suitable for growing productive grasses like *Cenchrus setigerus, Sporobolus helvolus, Dichanthium annulatum* etc. Overall, the current efforts certainly enhances the scope and utilisation of vast stretch of saline and degraded area of Banni and this would reduce the pressure on other available land resources.

1. INTRODUCTION

Man's relationship with his environment is a complex one. Primitive man managed to live as part of the natural ecosystem without altering its major characteristics. However, with the beginning of agriculture, man became increasingly sophisticated in his knowledge to modify an ecosystem in order to obtain the food, fodder or other eco-services he needed. In achieving this end, man has modified ecosystems by directing energy and materials from the system to serve his personnel needs without due considerations to the overall sustainability of the ecosystem. As a result, in many managed ecosystems signs of severe degradation and declining potentialities in supporting the life forms are becoming prominent.

Amongst the many ecosystems, grassland is one of the most affected system, which is clearly evident by sharp decline in its productivity and species diversity. The preeminent causes, which induce the grassland degradation include; overgrazing, soil erosion, nutrient depletion, salinization, pollution, disruption of hydrological systems, conversion of natural areas into croplands, monoculture plantations and ill-planned developmental activities. The environmental problems of grassland ecosystem are so enmeshed that it is very difficult to resolve which component, is threatening the sustainability of human life dependent on this ecosystem. To check the cycle of environmental decline, non-sustainable land use and socio-economic instability of the area must be regulated and efforts to restore the areas of acute degradation'as well as partially damaged grassland ecosystems are very essential. Therefore, it is an urgent prerequisite to develop an over-arching policy to conserve and manage the grassland resources in a sustainable manner. This would help in arresting the loss of biological diversity.

1.1 Grassland / Savanna

Grassland vegetation differs from forests in that the aboveground vegetation is completely renewed each year. Grassland is a landscape unit dominated by grasses (Coupland 1978, Yadava and Singh 1986). These grasses, belong to the family Poaceae (Graminae), which forms fourth-largest family amongst the flowering plant, and constitutes over 10,000 species belonging to 700 genera. On the other hand, Savanna are tropical or near tropical seasonal ecosystems with a continuous herbaceous layer, usually dominated by grasses / sedges and a discontinuous layer of trees and / or shrubs (Frost *et al.* 1986).Since the vegetative productivity of grasses is very high, herbivorous animals, especially large mammals, are favoured in the grassland community (Renner 1938). The best pastures are those in which grazing animals do not consume more than 70 to 80 per cent total herbage productivity of the grasses (Stoddart and Smith 1943). Looking at the physiology of grasses, the meristematic tissue of a grass leaf lies at its base, when the terminal portion is eaten off, it keeps on growing. Actually, grazing stimulates lateral branching at the base of the stem. Therefore, light to moderate grazing is always good for maintaining the grassland. However, heavy grazing should not be permitted, which in turn destroys seed stocks prior to dropping of the seeds or weaken the plant physiologically and inhibiting the seed production. Further, overgrazing produces a change in the kind and number of animals present. Increased populations of insects and rodents are a result, not a cause, of overgrazing.

Savanna is highly dynamic on temporal and spatial scales, and varies with changes in climate, primarily rainfall, soil nutrient content, fire regime and herbivory (Walker 1987 and Skarpe 1991). Grasslands are evolved under a system of grazing, drought and periodic fire (Anderson 1982). Either of these or a combination of all these factors maintain all the existing grasslands.

1.2 Importance of Grasslands

Mankind is sustained more by grasses than by any other group of plants. The relationship between man and grasses dates back to Paleolithic time

(Leafe 1988) and the existence of human life and quality would be impossible without grasses. In arid areas, rearing of livestock mainly depends on the extent and condition of the available grasslands. The importance of livestock in pastoral systems exceeds their value as sources of milk, meat and hides. Livestock often represent a means of accumulating capital and, in some societies, are associated with social status. They are assets that can reproduce and can be liquidated should cash be required. In addition to supporting livestock, grassland serves as sources of other significant economic products: leaves, seeds, tubers as food for human population, as well as medicinal plants, building materials, thatch, fencing, gums and other products important to the economics of rural populations (Sale 1981 and NRC 1983).

Grasslands, compared to the forests, support the highest densities of mammalian zoomass of the planet, and are still the basis of subsistence for millions of pastoralists and protect many vulnerable soil from rapid erosion. A large number of wild fauna which include 477 species of birds and 245 species of mammals reported are solely dependent on grasslands for their survival (Groombridge 1992). The biodiversity of grasslands is usually enhanced by moderate land uses such as grazing and periodic fire. In spite of all this, the grassland ecosystem has received much less importance and has been neglected in terms of conservation and proper management.

1.3 Grasslands of India

Grasslands extend over 24 per cent of the world's vegetation (Shantz 1954), however, prior to the impact of man and domesticated animals, its extension was approximately 40 per cent. In Asia the grassland accounts for 20 per cent of land cover (Premadasa 1990).

In India, grasslands constitute one of the major biomes. All the natural and semi-natural grasslands maintained by livestock / wildlife are collectively known as Rangelands. In India, 13,813 km^2 area of the land falls under this category (Singh, 1988). Between 1954 and 1962, the Indian Council of Agriculture Research (ICAR) conducted grassland surveys and classified the grass cover of India into five major types (Dabadghao and Shankarnaryanan 1973); *Sehima-Dichanthium, Dichanthium - Cenchrus - Lasiurus, Phragmites - Saccharum - Imperata, Themeda - Arundinella* and Temperate - Alpine cover. The physiognomy, phenology and diversity of grasses vary with rainfall, topography and type of soil. Therefore, depending upon the biotic influences and local variations in topography and soil structure, these five broad categories can still be subdivided into several grassland associations (Singh and Joshi 1979). The climax grasslands are supposed to be absent in India (Whyte 1964, Blasco 1983), but grasslands as secondary serai stage are common (Champion and Seth 1968). Therefore, they have been called as disclimax (Misra 1946), or pre-climax (Champion and Seth 1968) or sub-climax (Singh *et al* 1985). However, Rodgers (1986) has named the grassland of India as anthropogenic or Savanna.

1.4 Grasslands of Gujarat

In India, grasslands are mainly found in Gujarat, Rajasthan, Maharashtra, Western Madhya Pradesh, Uttar Pradesh and Brahmaputra valley. In Gujarat, the grazing requirements of the livestock are met from grasslands, forests, gauchers (village grazing land) and fallow lands. The grasslands, wastelands and gauchers are known as Common Property Resources (CPRs). Interestingly, the CPRs, which have an access for grazing, are gradually declining. They were 61.4 per cent of the land area in Gujarat during 1961-62 and decreased to 50 per cent in 1992-93 (Parikh and Reddy 1997). About 1400 km^2 area of Gujarat is maintained by the Forest Department as grasslands, of which 1295 km^2 is located in Kachchh and Saurashtra region of the State (Rahmani 1997). In Kachchh district, 800 km^2 is located in Banni and approximately 100 km^2 is in Naliya region. The grasslands are called as 'vidis' in Saurashtra and 'rakhals' in Kachchh. There are two kinds of 'vidis'; reserved and non-reserved vidis. The former is better-protected grassland, where, the grasses are harvested only after monsoon while the non-reserved vidis are less protected. In all, there are 166 reserve vidis in the state covering an area of about 759 km^2. Of these, 159 vidis covering a total area of 709 km^2 are located in Kachchh and Saurashtra regions while the remaining are in Panchmahal district of the state. The non-reserved vidis extend to an area of about 635 km^2 (Rahmani 1997). Besides these, there are a number of 'gauchar lands' (village grazing lands) available in the State.

1.5 Arid Region, Grassland and Livestock

The entire Kachchh district, which encompasses an area of 45,652 km^2 falls under the arid tract of the

Gujarat State. Due to scanty and high temporal and spatial variations in monsoonal rains, the region is more suitable for livestock based economy than the arable farming. Indeed a large single stretch of natural grassland, known as "Banni" is located in Kachchh district. Banni grassland encompasses an area of 3,847 km^2. This grassland, once referred as Asia's finest grassland, accounts for approximately 45 per cent of the permanent pasture and 10 per cent of the grazing ground available in the state (Parikh and Reddy 1997). In spite of all its importance, the Banni grassland has been under severe pressure due to many factors, which have gradually degraded most part of it.

1.6 Causes for Banni Degradation and Current Status

The structure and dynamics of grassland is the outcome of large number of environmental factors or determinants (constraints to the system). Vegetation changes in a system are the responses to and effects upon their environment by individual plants (Goodall 1963, Roberts 1987, Acker 1990). However, sudden changes in the constraints lead to modifications in the mechanisms, which generally disturb the system. The major natural and anthropogenic causes responsible for degradation of Banni are as follows:

Even though grassland species of Banni have developed a variety of drought adaptations, a severe drought, perhaps, is the most important natural factor responsible for its degradation. It is also important to note that, severe consecutive droughts, which were a very rare incidents (occurred twice; 1904 -1905 and 1968 -1969) during the period between 1901 and 1980 have increased abruptly during the recent years (1981-1996). Three consecutive severe droughts, the first of its kind in this century, occurred from 1985 to 1987 and another two consecutive droughts occurred in 1995 and 1996. This situation has predominantly affected the soil moisture and thereby hastened the process of grassland degradation.

Although, the inherent salinity was existing even during the early days in Banni, the rivers, which were flowing from the Kachchh mainland to Banni were not only depositing the detritus and maintaining the soil moisture but also leached the salinity of the area during good rainfall years. The construction of 6 medium dams namely Rudramata, Niruna, Nara, Kaila, Kaswati and Gajansar has nearly stopped the collection of water from 1603 km^2 catchment area except during the heavy monsoon years. Thus, natural leaching of the salinity of different parts of Banni is totally interrupted. In addition to this, seawater from the Kori creek entered the northern part of Banni due to the construction of Punjabi-road during the year 1965. Further, low or absence of vegetative cover in high saline areas encourages the wind to transport salt particles from the Rann to fertile Banni areas resulting further increase in salinity. The cumulative effect of all these factors is the increased salinity in nearly 90 per cent of the Banni grassland.

In addition to these, the Gujarat State Forest Department, as a measure to check the advancement of the Rann, has planted initially about 31,550 ha exclusively of *Prosopis juliflora.* The circumstances of Banni such as; successive droughts and increasing salinity provided more suitable condition for the growth and extension of this species, which has today become the most dominant species and is spreading at the rate of about 25 km^2 per year.

Grazing is another major problem in Banni grassland. Large herbivores are known to speed up the nutrient turnover rate in savanna (Ruess 1987, Ruess and McNaughton 1987). However, excessive or over grazing leads to massive degradation. During the normal rainfall years, livestock from neighbouring talukas and districts of Kachchh and even from other states, totalling to over 2 lakhs immigrate into Banni for grazing.

It is important to note that, high grazing pressure combined with stochastic events (temporary droughts, changes in soil conditions) may convert perennial vegetation into one dominated by ephemerals, but continuous heavy grazing prevents renewed change from ephemeral to perennial vegetation when weather conditions change (Christina, 1992). This situation leads to loss of soil cover, which further aggravates the degradation of the area.

The aforesaid issues brought a severe unsustainability in Banni grassland, which decreased the human population from 14,389 in 1981 to 10,949 in 1991 (24 per cent) and livestock population from 49,240 in 1982 to 26,084 in 1992 (47 per cent). Among the three regions (east, west and central) of Banni, the eastern Banni has already lost its capacity and the western Banni is slowly loosing its capacity to sustain both human and livestock populations. As a result, a maximum concentration of 55 per cent of the human (4149) and 65 per cent of the livestock population (7333) is located at central Banni region (GUIDE, 1998), exerting excessive pressures in this area which may lead to massive degradation due to over exploitation of resources. (For more details see *"Status of Banni Grassland and Exigency of Restoration Efforts*, 1998, by Gujarat Institute of Desert Ecology, Bhuj).

1.7 Actions Taken and Lacuna

Considering the seriousness of the grassland problem, many government and nongovernment agencies carried out investigations and suggested some remedial measures to improve the overall range condition of Banni. As a follow-up, many developmental projects have been implemented but with few perceivable results, as these projects lacked a basic ecological approach. Rejuvenation of Banni and restoring it into a sustainable productive ecosystem calls for a holistic ecological approach. Further, in the past, the major drawback of these development alternatives was that the development had become capital centred as opposed to people centred; it had even bypassed or marginalized people in its concern to build and construct.

1.8 Need for Grassland Restoration and Management in Kachchh

In the arid rangelands the grazing pressure ranges from 1 to 4 ACU (Adult Cattle Unit) per ha per year against the carrying capacity of 0.2 to 0.5 ACU per ha per year (Raheja 1966). As per these estimations one ACU of arid area requires 2 to 5 ha of grazing ground. However, the available grazing land, which includes all categories; i.e. good, fair, medium and poor condition grasslands, in the Kachchh district, is less than 2 ha per ACU. Therefore, the grazing requirement of the entire livestock in the district cannot be met from the existing grassland resources. The frequent droughts cause further loss of livestock owing to the shortage of fodder resources. Further, the process of urbanisation, agricultural expansion, industrial developments and mining are putting increasing pressure on the existing grassland resources. Under these circumstances, it is necessary that improvement programme in the existing rangelands be implemented and if necessary, complemented by raising fodder tree species (Paroda *etal.* 1980).

For the advancement of the backward tract in Banni grassland, an enlightened interest, sympathetic approach and effective implementation of restoration and management activities are essential to shake off the local people's inertia and awaken the people to the needs of improving the level of living. To achieve the aforesaid, it is essential to take appropriate measures to restore / repair and manage the degraded areas of Banni - the life supporting system of the pastoralists, so that, it can be sustained for the future generations.

1.9 Restoration

Range management has been defined as " the science and art of planning and directing range use so as to obtain maximum livestock production consistent with conservation of range resources". The range plants are broadly classified into three categories;

decreasers (highly nutritious and palatable members of the community that generally decrease with grazing pressure), increasers (less palatable species which increase due to over grazing) and invaders (under excessive grazing pressure the increasers will decrease and are replaced by unwanted weeds). Therefore, restoration activity is aimed to improve the quality and quantity of decreasers of an area into an optimum level (Owen 1980).

Restoration is the only way to improve the sustainability of Banni grassland, where degraded grassland currently support few people and where restoration would directly involve the preservation and encouragement of sustainable uses. Restoration research though practised on a small scale for a number of years in some developed nations, is relatively new field of investigation in developing countries (Jordan *et al.* 1979, NRC 1989) like India. Restoration of degraded lands is a challenging problem, and requires a thorough understanding of ecological principles. Therefore, Bradshaw (1987) called restoration as *"acid test for ecology"*, thus highlighting the difficulties involved in such tasks.

The restoration processes are affected directly by the level and types of degradation. Over utilisation by man beyond the carrying capacity results into fragile situation, which along with drastic disturbances makes it extremely vulnerable to future anthropogenic changes (Peters 1985; Peters and Darling 1985). For a successful restoration programme, it is essential to recognise the potential detrimental factors influencing the area. GUIDE has carried out a study to assess and understand the causes, its effects and magnitude of problems existing in Banni (GUIDE, 1998), so that appropriate steps can be taken in time to keep these disturbances at a minimum, and the ecological balance may be re-established at the earliest. Once symptoms of ecosystem deterioration become apparent, the only option left is to react to the situation and try to cure the problem by corrective measures (Singh 1988).

1.10 Approach of Gujarat Ecology Commission in Banni Restoration

Keeping the above in view, to overcome the identified problems of Banni grassland, the Gujarat Ecology Commission (GEC), a body set up by Government of Gujarat, initiated a research project on "Restoration of Banni grassland" during the year 1995. GEC has adopted a holistic approach in the design and implementation of the restoration of Banni by considering inter-linkages between ecological parameters. The Commission has proposed innovative demonstration schemes considering the ecology of Banni ecosystem, and by trying to work with nature rather than against it.

The approach differed from the earlier grassland development programme wherein only protection from the livestock grazing was provided by a trench fencing and the area was left under natural condition. However, GEC initiated eco-friendly approach by undertaking proper management inputs to nullify the effects of the detrimental factors, which caused the degradation, through people participation.

1.11 Objectives

The objectives set for the restoration of Banni grassland include:

- Development of grassland at suitable sites
- Development of the degraded, *Prosopis* infested and high saline areas into productive grassland
- Development of indigenous tree cover.
- Evaluate appropriate guidelines for sustainable management of Banni grassland.

The GEC has implemented the aforesaid activities through two institutes and a corporation:

1. Gujarat Institute of Desert Ecology **(GUIDE),** Bhuj - involved in the development of saline tracts of Banni with the following objectives:

- To demonstrate appropriate techniques (using different soil amendments) for saline land reclamation.
- To identify suitable grass species for saline areas and find ways to improve their productivity
- To assess the effects of restoration on the species diversity and biomass production in saline areas.
- To assess the changes in species diversity and biomass production in the restored, non-restored and *Prosopis juliflora* infested areas mainly to assess the effect of grazing and *Prosopis juliflora* on the distribution, abundance and productivity of different grass species.
- To demonstrate appropriate grassland (range) management techniques.

2. Vivekanand Research and Training Institute **(VRTI),** Mandvi - involved in the development of degraded lands with the following objectives;

- Development and reclamation of grassland areas affected by heavy grazing and infestation of *Prosopis juliflora.*
- Development of water harvesting structures to enhance the soil moisture of the area.
- Development of indigenous tree cover in the restoration plot.

2. STUDY AREA

2.1 Location

Banni, the largest single stretch of grassland in India, is located on the northern border of Bhuj taluka (23° 19' 23° 52' N latitude and 68° 56' to 70° 32' E longitude) of Kachchh district in the Gujarat State. It encompasses an area of 3,847 sq. km and forms a low alluvial tableland. The entire area is more or less flat and without any gradient. Banni has 52 villages, which are under 17 panchayats (Census 1991). The plains of Banni geomorphologically resemble an embayment, which is bounded by the Kachchh mainland upliftment in the south, the Pachchham upliftment in the north and the Wagad, and Bela upliftment in the east. In the southern part of Banni there is an intervening stretch of salty waste known as Little Rann of Banni, which separates the Banni from the mainland of Kachchh **(Figure** 1).

The name Banni was derived from a Kachchhi word 'Banna/', which means *"Banni hui"* in Gujarati (made up); signifying that the land has been formed by detritus. There are views that Banni was formed by the sediments brought down by the rivers such as Indus, Luni, Banas and Saraswati which, in the recent geological past, flowed through this area from the north and east (Kadikar, 1994).

2.2 Climate

The climate of Banni is arid. There are three predominant seasons; monsoon extends between end of June to September, October and November being the transition months, winter lasts from December to March and summer spreads between April to June. The temperature of Banni is high during most of the time and it reaches a maximum of 48-49°C during May-June (the hottest months). The winter temperature goes down to 10° C with January and February being the coldest months. The total annual rainfall, occurring through south-west monsoon between June and September, is very low with an average of 317 mm per year with a coefficient of variation of 65 per cent (GAU, 1989). The rainfall is extremely erratic and variable in distribution, therefore, droughts are a recurring phenomenon.

2.3 Banni Soil

The soils of Banni are inherently saline and consist of recent alluvium mixed at places with aeolian sandy deposit and the entire area has deep to very deep clayey and coarse textured soils in discontinuous patches. In Banni, soil material containing clay loam to silty clay loam is termed as moderately fine textured soils, which ranks first in distribution and covers 59 per cent of the total area. The salinity of the soil is highly variable from 1.0 (very low) to over 15.0 Mmhos/cm (very high). About 90 per cent of the Banni area falls under moderate to very high salinity and the pH ranges between 6.5 and 8.5. The soil salinity also changes with the depth of the soil horizon. Though, the subsurface water in Banni exists at shallow depth of about 3m, it is highly saline, thus not suitable for drinking or irrigation purposes. Further, the presence of high silt and clay content lessens the vertical and lateral movement of surface and subsurface water. About 70 per cent of the Banni area fall under very slow to slow permeability range (0.00 to 0.13 cm/hr) which subsequently leads to waterlogging in the low-lying areas during good rainfall years.

2.4 Vegetation

Banni supports the growth of perennial and palatable grasses of high productivity, which grow in low to moderate saline areas. They are *Sporobolus pallidus*, *Sporobolus helvolus*, *Dichanthium annulatum*, *Cenchrus ciliaris*, *Cenchrus setigerus*, *Desmostachya bipinata* etc. High saline areas are colonised by perennial grasses of low productivity and palatability such as *Aeluropus logopoides*, *Eurochondra* sp. etc. Among the tree species *Acacia nilotica* was once distributed all over Banni. The shrub and tree strata were mainly composed of *Prosopis cineraria*.

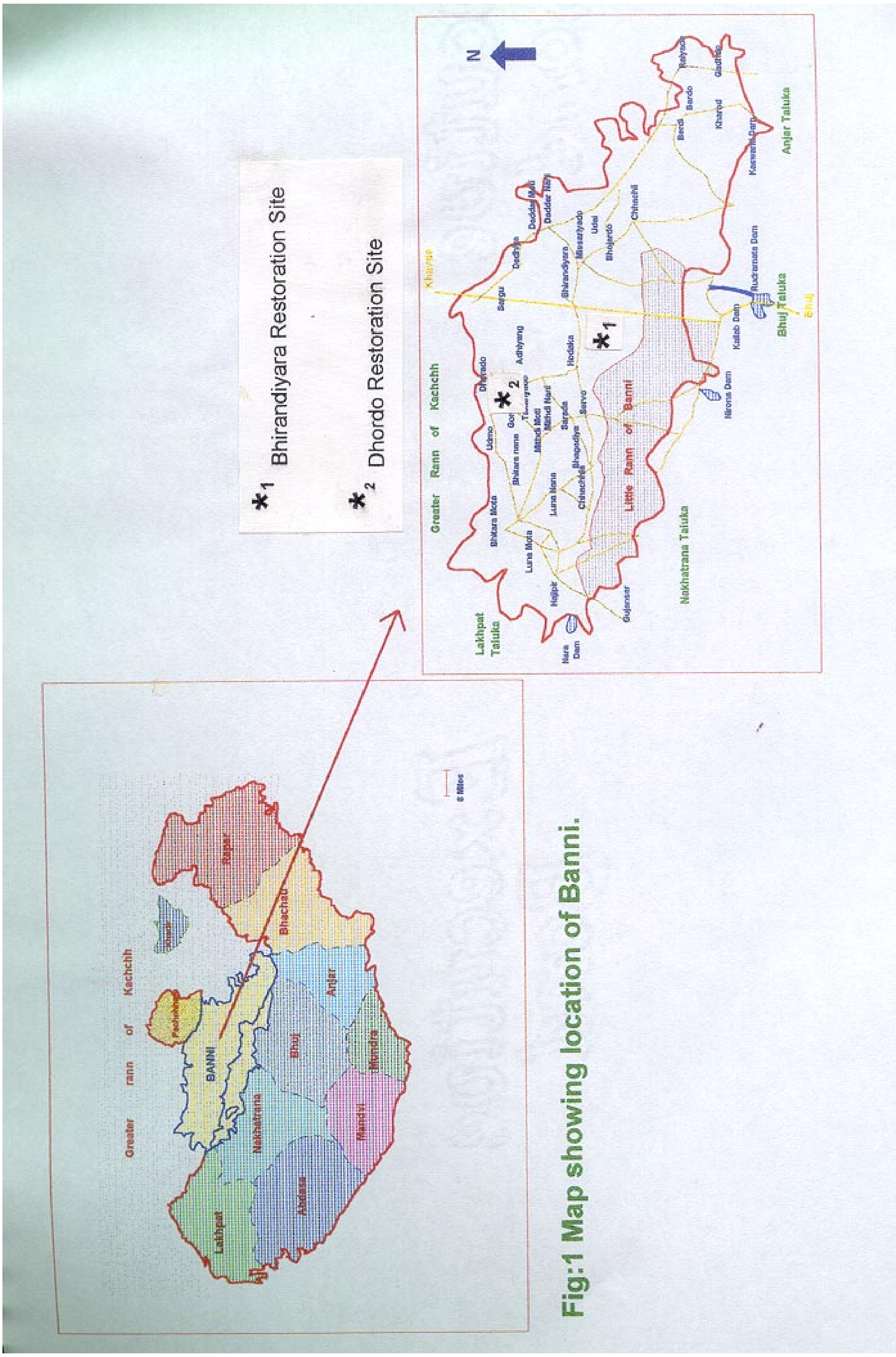


Fig. 1 : Map showing location of Banni

Acacia nilotica, Acacia leucophloea, Acacia Senegal, Salvadora persica, Salvadora oleodes, Capparis decidua, Tamarix sp. and *Prosopis juliflora.* Today, palatable grass and tree species like *Acacia* and *Salvadora* sp. though present, their abundance has decreased very significantly due to the massive invasion and dominance of *Prosopis juliflora.*

2.5 Fauna

The wild animals of Banni include: Blue bull, Chinkara, Black buck, Blacknaped hare, Wild boar, Jackal, Grey wolf, Caracal, Hyena, Fox, Jungle cat, etc. It also supports a rich diversity of Avifauna, Herpatofauna, and Invertebrates. Further, the water bodies of Banni, during good rainfall year forms important staging ground for thousands of migratory cranes and also support over 150 species of migratory and resident birds.

2.6 People and Livestock

Banni has a very low population density, 3.6 person / km^2 (as per 1991 census) and, this very much resembles the density of human population in most of the other arid regions of the world. The residents of Banni are called Maldharies. Muslims, Hindus and Vadhas are the three major communities inhabiting the area. There are 15-20 Maldhari muslim castes in Banni and they speak Kachchhi, a dialect close to Sindhi language.

Livestock is the mainstay of the inhabitants of Banni, which constitutes the major bulk of their assets. Out of 10,949 people in Banni (1991 census), 2443 people are entirely engaged in livestock rearing and other allied activities. Their interest mainly centres on livestock breeding and the area is a well-known cattle-breeding tract of Gujarat. However, due to establishment of milk co-operative societies in early 1980's, the people of Banni are slowly getting inclined towards selling of animal products such as milk, ghee etc. A rough estimate shows that the total milk transported from Banni villages to Bhuj via Bhirandiyara alone amounts to 14,240 litres per day, which gives an income of Rs 1,538 / household / month.

2.7 Land Ownership and Grazing Regulations

During the period of princely rule, the then Maharao declared Banni, with an area of 2,144 km^2 as a reserve grassland (Rakhal), where only grazing by milching cattle and buffalo was permitted while sheep and goats were strictly prohibited. Further, Maldharies were not permitted to permanently settle in Banni. Hence, nomadism had prevailed for many years. After independence, Maldharies of Banni have turned to pastoralistic mode of life.

In Banni, human settlements / villages are located approximately at a distance of 5 to 15 km and all the settlements are established in or around water tanks or jheels mainly to ensure drinking water for themselves and their livestock. Unlike many other parts of Kachchh, the ground water in Banni is highly saline. The sweet water, stored in "tanks" or "jheels" after monsoon, is utilised for a few months before it disappears through infiltration and evaporation. During the rest of the year the infiltrated water, trapped in shallow depths in a layer "floating" above the saline ground water is utilised by digging shallow wells locally called "virda". Generally it takes 20 days to 2 months for a "virda" to become saline, depending up on the withdrawal, then a new "virda" is dug few meters away. Virdas are owned by families and a single family may own 5 to 15 virdas in a village. Though drinking water can be obtained from any "virda" if required, water for cattle has to be used only from one's own virdas.

In older times, these virdas played an important role in regulating the livestock grazing. Since no sweet water was available in Banni, the livestock grazing was restricted only in the vicinity of one's own village. However, today with the installation of pipelines, which supply water from Rudramata, Mamuara and Lakhond tubewells to Banni, the scenario has changed and the water is no longer a factor, which governs the livestock grazing. The 600 km long network of Banni pipeline is damaged by the maldharis at places for providing drinking water to their livestock. This has also encouraged the massive immigration of livestock from other areas, thus, leading to overgrazing and degradation of the area.

3. RESTORATION APPROACH

As a pilot measure, the restoration of Banni grassland was initially (for the year 1996) aimed to cover a total area of 500 ha at 5 different sites of Banni. During the successive years it was planned to gradually extend it into several other areas of Banni. However, due to administrative and local issues in acquiring the land, the restoration programme could be successfully launched only at two sites; one located at 11 km before Bhirandiyara and the other at Dhordo village covering an area of 15 and 200 ha respectively. The requirements and implementation activities carried out to improve the status of the restoration sites and to develop the grass and indigenous tree cover in the area are explained in the successive paragraphs (**Figure** 2).

However, it is important to state here that the natural recovery following degradation is a slow process; it depends on time and space, and is influenced by geographical and climatic factors and ecological conditions of the site. Therefore, a successful restoration programme attempts to accelerate the natural recovery process artificially in order to achieve the goal in a short time. In order to re-begin performing the productive and protective functions, a degraded land needs human assistance, i.e. protection, pre-treatment for habitat rectification such as; slope modification, nutrient and organic matter amendments, etc. (Singh and Jha, 1992).

3.1 Protection

The Banni grassland could be improved only in the good rainfall years. Since good years are generally followed by droughts in a cycle of every 3 years or sometimes alternative years, the best method to improve grasslands are based on the fact that an overgrazed land is protected from frequent grazing, the productive perennials, quality grasses replace the undesirable annual grasses. Protection from grazing allows the perennials to produce large quantities of seeds. Thus depending on the condition of a site, a continuous protection from grazing develops the ground layer principally made up of perennial grasses (Kanodia and Patil, 1983). The same improvement can be achieved but at a slower rate, with either deferred or rotational grazing system where the grasses are protected up to seed dispersal or as under pasture management systems. Therefore, the first step in any restoration strategy, of course, is to protect the disturbed habitats and communities from being further wasted, and from losing the extant genes (Singh and Jha, 1993).

As a measure to protect the Bhirandiyara restoration site from livestock grazing, a trench fence consisting of 1.2 m width and 1 m deep was laid along the periphery of the site. There are views that trench fencing is not a foolproof method to protect the grass plot from cattle. However, its effectiveness in the protection, depends upon the width and depth of the trench. Therefore, a barbed wire fence around the site was also raised to ensure double protection from any kind of grazing. It has been reported that the protection of grasslands with the help of barbed wire fencing increased forage production of better grasses (Bhimaya et. al. 1967, Ahuja 1977, Kanodia et. al. 1978). At Dhordo restoration site, due to the coverage of vast area of 200 ha, it was decided to have only trench fencing. But, to ensure full protection from cattle, a 2 m wide and 1.5 m deep trench was dug along the periphery of the plot, which covers a length of 6000 m. The mud removed from the trench was also used to raise a 1.5 m high mud wall on the inner fringe of the trench. This ensured a complete protection from cattle. This method of fencing though less expensive as compared to barbed wire fencing, requires maintenance every year. This trench, apart from its cattle proof function, also helps in harvesting the rainwater due to its vast length, depth and width.

3.2 Removal of *Prosopis juliflora* and Other Weeds

Prosopis juliflora infestation is believed to be the major cause in reducing the productivity of pastureland and hinder the growth of grasses. Unwanted thorny bushes need to be removed out mechanically or manually to eliminate the

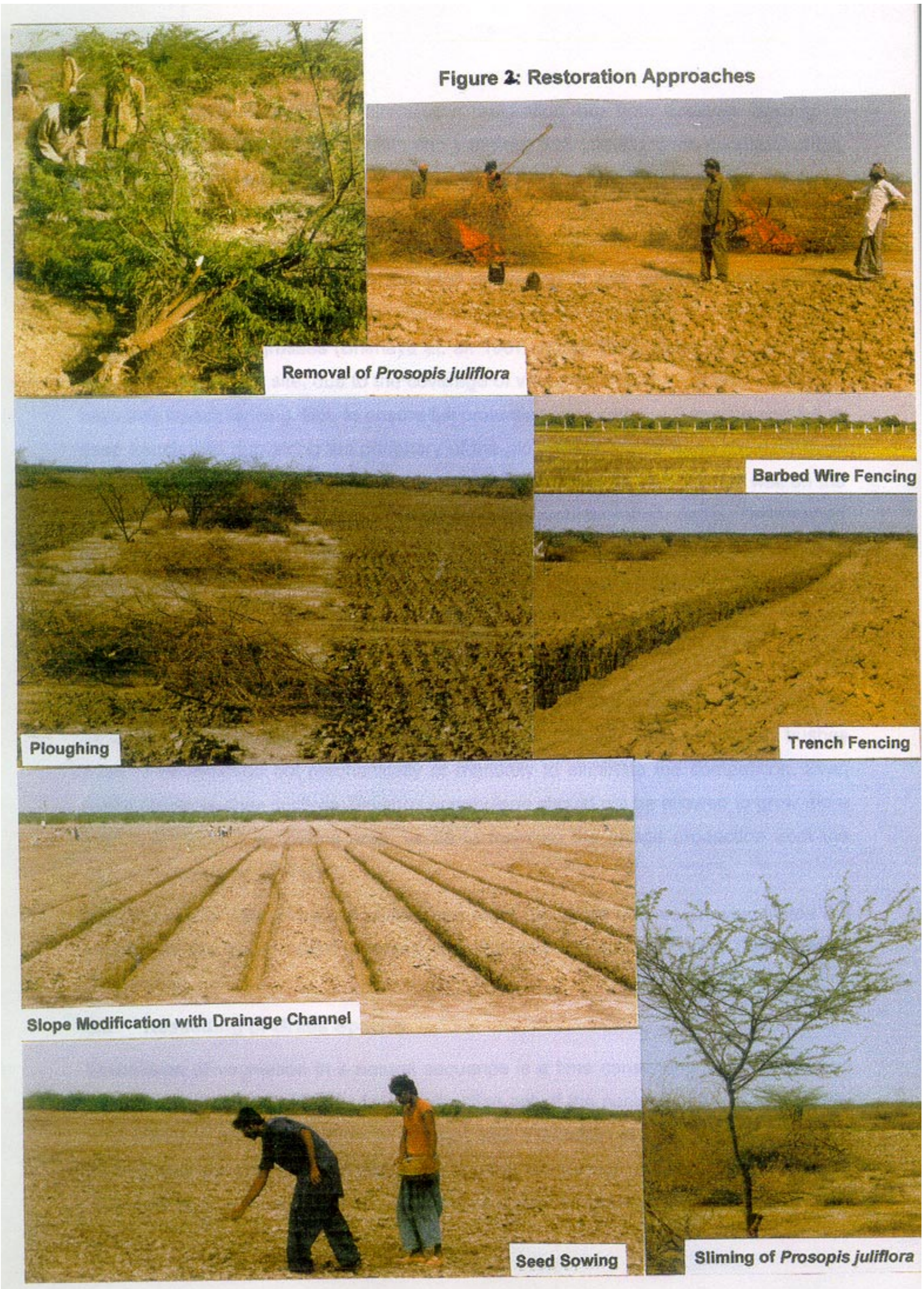


Figure 2: Restoration Approaches

competition. Even useful fodder bushes such as *Zizyphus nummularia* should not be allowed to grow more than 4 per cent in a grazing area, so as to maintain the forage production from the pasture (Ganguli *et. al.* 1964).

With the above view, *Prosopis juliflora* and other unwanted bushes growing inside the restoration site were totally uprooted with the help of Gujarat Forest Development Corporation.

3.3 Reseeding of Grass Species

Succession of vegetation in a natural sequence is a time consuming process and can be expected to succeed in the desired direction only if the nucleus of the plant material is available in productive stage on a given site. Plantation of seed slightly below the surface after scratching it or in strips with appropriate species of grasses is the quickest and most ensured method of improvement of degraded grassland (Kanodia and Patil, 1983).

For reseeding, first preference was given for indigenous grass varieties, which normally grow under arid climatic and soil conditions of Banni. Therefore, indigenous seeds were obtained from Banni Development Agency, Bhuj. Apart from this, seeds were also obtained from Indian Grassland and Fodder Research Institute, Jhansi. The indigenous species such as; *Cenchrus setigerus, Sporobolus sp., Eurochondra* sp., *Dichanthium annulatum, Chloris barbata and Cenchrus ciliaris,* were selected for sowing in the restoration site. The selection of indigenous species was based on the fact that they have genetically acquired several adaptations to survive in the harsh climatic and soil conditions. Therefore, they were expected to thrive well in the restoration sites where more suitable conditions for grass growth were already created. Apart from this, species such as; *Chrysopogan fulvus* and *Pennisetum pedicellatum* were also sown in small quantities. The later species was not reported from Banni area. The performance such as growth and productivity of this species in the restoration site would help in planning for future large-scale introduction of such species in entire Banni area. The reseeding activity, it is hoped, would increase the seed bank of the area and thereby enrich the grass density and diversity of the restoration site.

In arid area, under rainfed conditions, the sowing of grass seeds is normally done in the months of June / July with the onset of monsoon. To enhance the germination and uniform distribution of seeds, the seeds were mixed with soil and farmyard manure. Then they were thoroughly mixed by sprinkling water. This reduce the transport of seeds through wind and the moisture in the seed mixture hastens the process of germination. Care was taken that, the seed sown was covered by 1 to 2 cm soil layer. Since, the grass seeds are too small, the stored germplasm is insufficient to support the germination and growth of seedlings from deeper soil layers. The stocking rate of seeds varied with the species. Normal stocking rate of seed reported is; 2.5 kg/ha for *Dichanthium annulatum,* 5 kg/ha for *Cenchrus ciliaris* and *Cenchrus setigerus,* 5 kg/ha for *Sporobolus* sp. etc. to 75 kg/ha for *Lasiurus* species. However, keeping the view of the near absence of seed bank in the restoration sites, nearly 3-4 times higher seed rate than the normal were stocked.

The Bhirandiyara restoration site was divided into four sub-compartments, each covering an area of approximately 3.4 ha. The first compartment, covering an area of 3.4 ha was kept under natural condition (Compartment 1), where the fencing (trench and barbed wire) ensured complete protection from livestock grazing. Pure as well as mixed combination (for Eg. *Cenchrus* sp. with *Sporobolus* sp.) of grass seeds were sown within the compartment, however, a strip (10m width and 250 m length) covering an area of 3750 m^2 was kept completely under natural condition where no sowing of grass seed was undertaken. The basic view was that, the area devoid of seed sowing resembled very much to that of the area out side the fenced area of the site. The only difference between these two was that the former received protection from grazing while the later was subjected to grazing pressures. Hence, a comparison of the productivity of grass species of the said area with that of outside the fenced site would provide the effect of grazing pressure that existed in the area. The mixed combinations of seeds were used to understand the better species association in terms of productivity.

At Dhordo restoration site, the whole area was divided into 30 m wide strips. Ploughing, broadcasting of grass seeds and adding of farmyard manure was carried out at alternative strips.

3.4 Fertiliser Application

In the natural pastures of arid regions, scope of fertilisation is limited mainly due to uncertainty of rainfall. Further, due to selling of cow dung from Banni, the natural supply of manure has been considerably reduced. It has been reported that, about a ton of cow dung consists of 75 per cent water and remaining consists of 4.5 kg nitrogen, 2.3 kg phosphoric acid and 4.5 kg potash and that the cattle returns nearly 75 per cent nitrogen, 80 per cent phosphoric acid and 90 per cent potash obtained from her feed (Owen 1980). The two-way system; intake of nutrients through grass feed and its release through dung facilitate almost no loss or negligible loss of nutrients from the grassland area. However, the disruption of this cycle, through selling of cow dung, in Banni, has gradually affected the soil nutrients of the area, which in turn has affected plant growth. Therefore, to increase the soil nutrients of the restoration site, farmyard manure was added at the rate of 2 tonnes per ha. This, apart from improving the nutrient status of the degraded land would improve the physical properties of the soil such as permeability, soil structure etc. Also, the chemical binding of dung with that of soil is known to reduce the soil salinity to some extent.

3.5 Legume Introduction

Grass-legume mixtures are always desirable because of their complementary functions in providing nutritive and palatable forage for livestock. Legumes usually maintain their quality better than non-legumes even at maturity and being rich in protein they enhance the forage value and also add substantially the needed nitrogen to the soil. Thus, grasses are directly or indirectly benefited by the use of nitrogen components manufactured by the legumes. Legumes are considered as useful and the cheapest source of nitrogen in pastures. On death and decay of the legume plant, their roots and root nodules break down in the soil and release their stored nitrogen, which then becomes available to the associated crops.

Therefore, legume species like *Afylosia* sp., *Sesbania* sp. and *Stylo hamata* were sown in the restoration sites. Further, species such as *Sesbania* produces high quality fodder, that can also be used as cattle feed.

3.6 Soil Amendments in Bhirandiyara Restoration Site

The restoration site selected at Bhirandiyara was located in a highly saline track of Banni. In this site experimentation on salinity reduction and control was undertaken to improve the grass diversity and productivity. This site was divided into four equal compartments, of which, compartment 1 is left under natural condition where no soil modifications were carried out. Compartment 2 was ploughed to a depth of 50 cm to improve the soil permeability, water infiltration and to break up-surface crust. In this compartment, organic manure was also added at the rate of 2 tons/ ha.

To leach the salinity of the research site, a 5 m wide gentle slopes with a height of 30 cm and with 50 cm deep and 50 cm wide drainage channels were dug in the compartment 3. Similar activities, with changes in the width of the slopes to 3 m and height of the slopes to 50 cm were made in compartment 4 to study the effects of increasing the slope height on the grass species diversity and productivity. The compartment 4 was further sub-divided into; half the slopes and the trench facing northwest direction and the other half facing east-west direction. The basic view of this amendment was to study the effects of wind borne salt deposition on the diversity and productivity of grass species growing on the slopes facing towards and against wind direction. It is hoped that this will help in generating an additional information on the deposition of salt particles through wind action and its impacts on the productivity of different grass species growing in the area.

3.7 Soil Amendments in Dhordo Restoration Site

The Dhordo restoration plot encompasses an area of 200 ha (width 1km x length 2km), located near village Dhordo. The whole area of the site was divided into 30m wide strips. Ploughing, adding of farmyard manure and sowing of grass seeds were carried out in every alternative strips. *Prosopis juliflora* grown inside the fenced site was removed, except for few *Prosopis juliflora*, in which the side branches were removed with a view to change the architecture of the plant. There is a common view that the spreading cover of *Prosopis juliflora* reduces the underneath ground cover and that the changed architecture would help in supporting the underground vegetation. Further, the tree may also act as a windbreaker.

4. METHODOLOGY

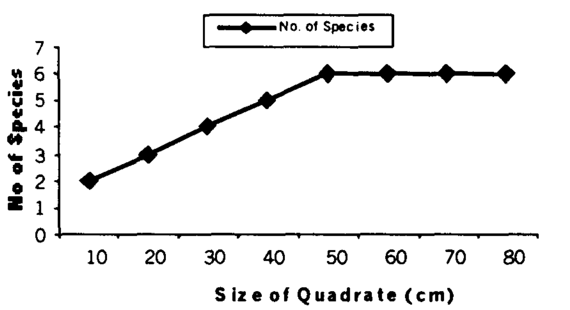
The vegetation data was collected from two restoration sites; Bhirandiyara and Dhordo and it's adjoining areas located outside the restoration sites. Further, to understand the effects of *Prosopis juliflora* on grass plant diversity and productivity, data was collected from such infested areas also. Even though several management inputs such as protection, reseeding, fertiliser application and soil amendments were carried out to hasten the recovery process of the restoration sites, all these efforts would not be successful with out appropriate rainfall. Therefore, the severe droughts, which prevailed during the year 1995 and 1996, created a serious hurdle on the recovery of restoration sites. During this period, the total rainfall recorded in Bhuj taluka was 152 and 87 mm respectively and this rainfall was 56 and 75 per cent less than the normal rainfall recorded (328 mm) for the taluka. Therefore, the efforts of the restoration activities at the two sites could be seen only after the 1997 monsoon i.e. from September 1997 to December 1997 (see limitation of data).

4.1 Field Data Collection Method

Quadrate method was used to collect the data on vegetation (species diversity and biomass) in the restoration and adjoining sites of Bhirandiyara and Dhordo. The size of the sampling quadrate was fixed to 0.5 x 0.5 m (square) based on the nested plot method **(Figure 3).**

The nature of plants causes a clear and a slow-changing spatial pattern in the distribution of species. Often patchiness in the environmental variables, restrict the dispersal of propagules and clonal growth, bring about a patchy distribution of plants of a species. The increase in the sampling number or replication of sampling than the minimum required number allows the precision of the generalisation to the whole study area to be measured. Therefore, a sampling strategy was designed to compensate for this patchiness and to give an accurate representation of the species in the whole study area. In total 35 sampling sites, covering an area of 25 x 25 m were fixed within the Dhordo restoration plot. In all the 35 sampling sites, three sampling quadrates (0.25 m^2) were laid starting from September 1997, and thereafter, every fortnightly for the rest of the study period. The data collection ended during late November 1997 at Dhordo (due to harvest of grass) and in December 1997 at Bhirandiyara site. During the study period, a total of 428 sampling were carried out at Dhordo restoration site, which includes 258 samples in the unploughed area and 170 in the ploughed area of the restoration site. In the degraded and *Prosopis juliflora* infested areas of Dhordo, 48 samples were carried out at each site. At Bhirandiyara, 4 sampling sites covering an area of 25 x 25 m (625 m^2) was fixed in unploughed and ploughed area where two samples at each sampling sites were carried out at fortnightly intervals. In the three slope areas, i.e. broad, vertical and horizontal, 8 samplings were carried out in each slope category. Thus, during the study period, a total of 200 samples which encompasses 40 samples in each amendment were carried out within the restoration site and 36 in the unprotected area in the nearby vicinity of Bhirandiyara restoration site.

Figure 3: Species Area Curve Method



In each sampling quadrate, data on plant species, its cover, frequency and biomass were recorded. Braun-Blanquet scale was used to estimate the cover of the grass species. The sampling area was divided into 5 cover classes; <1 per cent, 1-5, 6-25, 26-50, 51-75 and 76-100 per cent. The great advantage of this scale method as compared to more complicated surveying, is that it is less time consuming. This method however, is not accurate mainly due to subjectivity in the estimate. To avoid such inaccuracy, the designated classes of the cover in the area were defined initially through orientation training of the field research staff.

Data on aboveground biomass was collected using harvesting method. Care was taken to harvest the aboveground biomass at similar height, i.e. close to ground level. The harvesting of aboveground biomass was carried out between September 1997 to November 1997 (in Dhordo) or December 1997 (in Bhirandiyara) at a periodic interval of 15 days. The aboveground biomass was packed in polythene bags and site details were labelled on the bags. Then it was sorted into species at the laboratory and was dried under natural sun light for several days. After complete drying, the dry weight of each species in each sample area was taken by using Mettler precision balance.

The fresh weight was not considered because it is not an appropriate measure (Bullock 1996). It varies with the moisture content of the plant and the moisture loss during transportation to the laboratory.

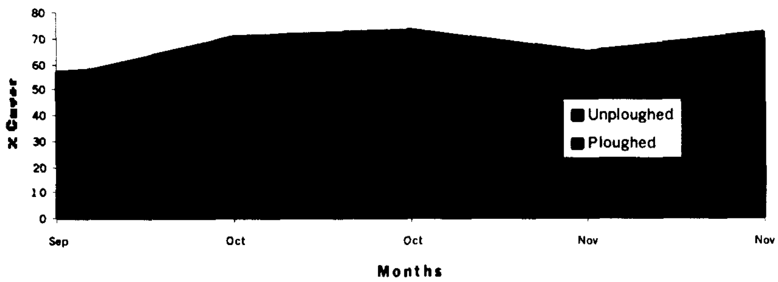
Within the quadrate, soil samples were also collected to assess the microhabitat condition and to understand the effects of soil parameters such as salinity and pH on the distribution and production of plant species. The sampling was done at two depths, i.e. the top soil and at a depth of 30-40 cm. The reason for restricting up to a depth of 30-40 cm was due to the fact that the grass root system generally utilises only 30 cm of soil depth. Singh and Yadav, (1993) reported that 93 per cent of the grass root materials were found up to 0-30 cm soil depth. The samples were analysed through soil testing laboratory of Agricultural Department, Bhuj.

5. RESULTS

5.1 COVER

The phenology of grass species occurring in grassland change immediately after a few showers. After receiving sufficient moisture, the seedlings of annuals and perennials start emerging from the seeds and sprouting of perennating buds, and are followed by vigorous vegetative growth, which gradually converts the area into lush green. The grass cover protects the soil from erosion and reduces the soil moisture loss due to evaporation. In the present study, the grass cover recorded in the restoration site showed a gradual increase while, it was maximum soon after the rainfall (September and October) in the unprotected and *Prosopis juliflora* infested areas and it decreased during the subsequent post monsoon season.

Figure 4: Monthly Variation of Cover in Unploughed and Ploughed area of Dhordo Restoration Site



5.1.1 Dhordo Restoration Site

At Dhordo, there was a marked variation in grass cover at three study sites, i.e., restoration site (site A), outside unprotected area (site B) and *Prosopis juliflora* infested areas (site C). The restoration site was broadly classified into two categories; unploughed area where no soil working was carried out and ploughed area where soil working such as ploughing, adding of farmyard manure and reseeding of grass species were undertaken. The grass cover estimated in the ploughed and unploughed area of site A gradually increased from 56.7 and 54.7 per cent in September to 67.4 and 72.1 per cent respectively at the end of November, with a slight fall (57 and 65 per cent) in the first fortnight of November (**Table** 1). Further, the unploughed and ploughed area did not record any significant variation in grass cover between the initiation and the end of the study period. Nevertheless, the grass cover was slightly higher in unploughed areas since October when compared to ploughed area (**Figure 4 and Table** 1).

Contrary to this, unprotected and *Prosopis juliflora* infested areas showed very low availability of cover, which during the study period decreased from 15.4 to 10.7 per cent and 30.7 to 8.3 per cent respectively. However, site C showed a higher cover than site B during the initiation of the study **(Table 1).**

A comparison between unploughed protected area (restoration site) and unprotected area (site B), which have similar climo-edaphic conditions,

Figure 5:Monthly Variation of Cover in Unploughed area Of The Restoration Site and Unprotected Area of Dhordo

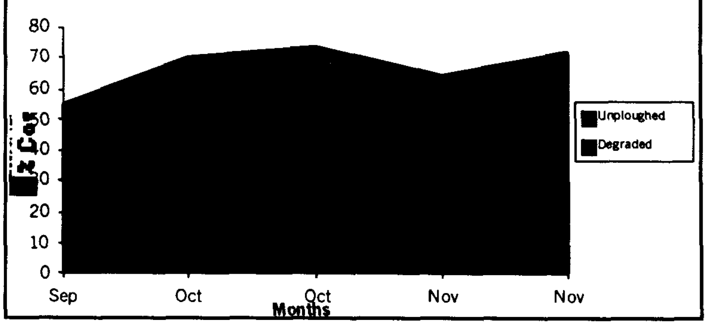


Table 1: Changes in Monthly Cover at Dhordo Restoration Site

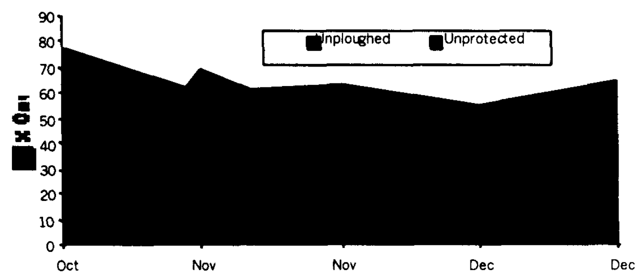
Site Details	Sep. '97	Oct'97	Oct'97	Nov.'97	Nov.'97
Restoration site - Ploughed Area (site A)	56.7	61.2	65.0	57.4	67.4
Restoration site - Unploughed Area (site A)	54.7	70.5	73.6	64.8	72.1
Unprotected Area (site B)	15.4	18.8	9.4	12.5	10.7
Prosopis Area (site C)	30.7	11.1	14.2	17.5	8.3

Table 2: Per cent Grass Cover Recorded in Different Sites at Dhordo

Site Details	Grass cover in September "97	Grass cover in November '97	Difference	Remarks
Restoration site - Ploughed	56.7	67.4	10.7	Increase
Restoration site - Unploughed	54.7	72.1	17.4	Increase
Unprotected Area	16.7	10.6	-6.1	Decrease
Prosopis Area	30.7	8.3	-22.4	Decrease

showed significant variation in grass cover. The grass cover of the former was 3.6 to 6.7 times higher than the latter during the entire period of study **(Figure** 5). This clearly demonstrated that grazing pressure in the unprotected area was significant. The **Table 2** shows the increase in cover by 10.7 and 17.4 per cent in the ploughed and unploughed area of site A while, it has decreased to 6.1 per cent at site B and 22.4 per cent at site C.

Figure 6: Monthly Variation of Cover at Unploughed area of Restoration Site and Unprotected Area of Bhirandiyara



5.1.2 Bhirandiyara Restoration Site

At Bhirandiyara, the monthly mean cover in the restoration site was 49 per cent at the initiation of the study in October and thereafter it showed a slight increase in November and remained almost stable up to the first fortnight of December, except that, it showed a slight fall in the second fortnight of December **(Table** 3). In the unprotected (outside) area, maximum cover was recorded in the first fortnight of November (69.4 per cent) which gradually decreased during the post monsoon period and attained a minimum of 19.4 per cent at the end of December. Thus, initially (first fortnight of November) the unprotected area showed a higher cover than the restoration site which then decreased significantly by the end of the study, indicating clearly the effects of grazing pressure on the unprotected area **(Table 3** and **Figure** 6).

The grass cover recorded under various amendments of the restoration site showed similarities in certain areas and variation in others. The cover estimated was very high (76.9 per cent) in the unploughed area and drastically low (17.5 per cent) in the narrow horizontal slopes. Interestingly, looking at the various amendments of the restoration site, the cover showed a decrease during the study period in the unploughed, ploughed and broad slopes whereas it showed an increase in the narrow vertical and horizontal slopes. The unploughed area in the restoration site had higher cover availability during the initial and end of the study period while, ploughed area exhibited a slightly higher cover during the middle period **(Figure** 7), i.e. first fortnight of November to first fortnight of December. Among the three types of slopes in the restoration site, almost similar cover

Table 3: Difference in the Grass Cover in and outside the Bhirandiyara Site.

Details of Plot	Oct.'97	Nov.'97	Nov.'97	Dec.'97	Dec.'97
Restoration site - Unploughed	76.9	60.0	63.1	55.6	65.0
Restoration site -Ploughed	55.6	68.1	61.9	64.4	51.9
Restoration site-Broad Slope (5x150)	50.0	35.0	50.0	46.3	38.8
Restoration site -Vertical Slope (3x150)	46.3	56.3	50.0	49.4	50.6
Restoration site -Horizontal Slope (3x150)	17.5	50	40.6	51.3	45.6
Monthly Mean Cover in the Restoration Site	49.26	53.88	53.12	53.4	50.38
Unprotected Area	*	69.4	46.9	43.8	19.4
% Difference Between Restoration and Unprotected site		28.7	-11.7	-17.9	-61.5

** data not obtained*

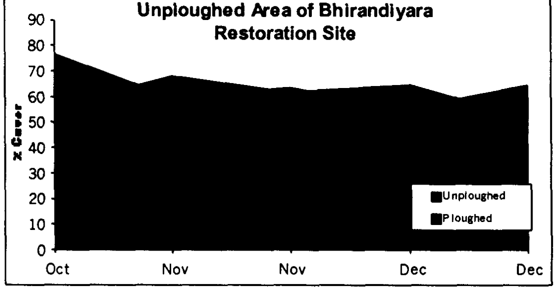


Figure 7: Percentage Cover at Ploughed and Unploughed Area of Bhirandiyara Restoration Site

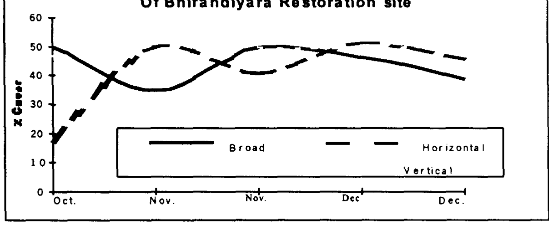


Figure 8: Cover Availability on Different Slopes Of Bhirandiyara Restoration site

availability was recorded at broad (50 per cent) and narrow vertical slopes (46.3 per cent) while on the narrow horizontal slopes it was low (17.5 per cent) during October. However, at the end of December the narrow vertical (50.6 per cent) and horizontal slopes (45.6 per cent) had the maximum cover which in turn decreased to 38.8 per cent on the broad slopes. Overall, narrow vertical slopes showed a higher cover than other two slopes except in October and first fortnight of December (**Figure** 8).

5.2 SPECIES DIVERSITY

Diversity is the central theme in ecology. Species diversity is a very useful parameter for comparison of two or more communities especially to study the influence of biotic disturbances or to know the state of succession and stability in the community. Shannon index of general diversity was estimated for the study sites (in and around Dhordo and Bhirandiyara restoration sites) using the biomass values of different species.

Table 4 and 5 highlight the species diversity recorded in the Dhordo and Bhirandiyara restoration site. Maximum diversity was recorded in the Dhordo restoration site while it was low at Bhirandiyara restoration site and the surrounding areas. Interestingly, the diversity of the Bhirandiyara restoration site was even far lower than the unprotected (site B) and *Prosopis juliflora* infested areas (site C) of Dhordo. Further, in Dhordo, the species diversity was not affected by the soil amendments, where the diversity index estimated for unploughed (H'= 1.02) and ploughed areas (H'=1.03) remained same. However, a slight variation in diversity was registered between the restoration site and the unprotected area (site B) as well as the *Prosopis juliflora* infested areas, which are located adjacent to the restoration site. The diversity of *Prosopis juliflora* infested area (H'= 0.95) was slightly higher than unprotected area (H'=0.88) (**Table** 4).

At Bhirandiyara, the diversity of the restoration site was far higher (H'=0.6) than the unprotected area (H'= 0.24), which is located adjacent to it. A little variation in diversity was recorded under various amendments in the Bhirandiyara restoration site. Among the different amendments, ploughed (H'= 0.66) area showed a higher diversity than the

Table 4: General Species Diversity Index at Dhordo Site

Site Details	General Diversity Index	Rank
Ploughed Area (Restoration site)	1.02	2
Unploughed Area (Restoration site)	1.03	1
Unprotected Area (site B)	0.88	4
Prosopis juliflora infested Areas (site C)	0.95	3

Shannon index (H) = -E [(ni/N) log (ni/N)], "ni"is the biomass ofith species, "N" is biomass of all the species

Table 5: General Species Diversity Index at Bhirandiyara Site

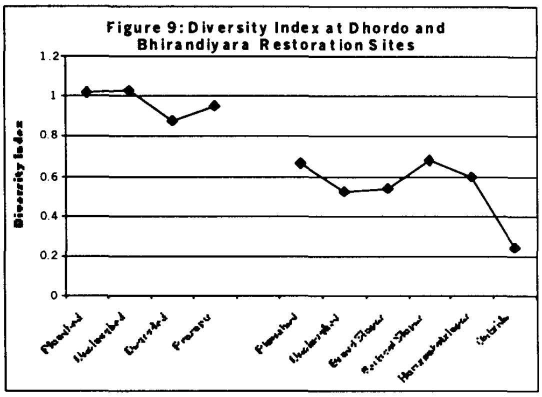
Amendments Details	General Diversity Index	Rank
Ploughed Area (Restoration site)	0.66	2
Unploughed Area (Restoration site)	0.52	5
Broad Slopes (Restoration site)	0.54	4
Vertical Slopes (Restoration site)	0.68	1
Horizontal Slopes (Restoration site)	0.60	3
Mean diversity in the Bhirandiyara Site	0.60	
Unprotected Area	0.24	6

unploughed area (H'=0.52). However, maximum diversity of the Bhirandiyara restoration site was recorded in the narrow vertical slopes (H'= 0.68). All the three categories of slopes reflect higher diversity than the unploughed area **(Table 5 and Figure 9).**

5.2.1. Species Recorded at Dhordo

In Dhordo, total 25 species belonging to 20 genus were recorded in the restoration site, which in turn decreased to 18 species (72 per cent) in the unprotected area (site B) and 17 species (68 per cent) in the *Prosopis juliflora* infested area (site C).

The occurrence of species such as Cenchrus ciliaris, Cyperus haspan, Chrysopogan fulvus, Scirpus sp., Setaria pallide, Themeda triandra, Tragus sp. and Sporobolus pallidus was restricted only at the restoration site whereas Sporobolus helvolus, Aeluropus logopoides, Dichanthium annulatum, Tetrapogan tenellus, Tragus sp., Chloris barbata, Cyperus rotundas, Echinocloa sp., Cenchrus setigerus, Eragrostis sp., Dinebra rotroflexa, Gandhiro, Digera rnuiicata, Aristida funiculata and Cressa erotica are some of the species found common in all the three sites (A, B and C) at Dhordo **(Table 6** and **Figure** 10).



5.2.2. Species Recorded at Bhirandiyara

At Bhirandiyara, in total 12 plant species belonging to 11 genus were recorded, which in turn decreased to 6 species (50 per cent) in the unrestored area. Further, within the restoration site, the number of individuals of the species fluctuates under different soil amendments. The species occurrence was high at unploughed area (91.7 per cent) followed by vertical slopes (75 per cent). In other areas, about 66.7 per cent of the species were recorded. *Cyperus haspan, Cyperus rotundus,* Scirpus sp., *Sporobolus helvolus, Aeluropus logopoides* and Cressa *erotica* are the common species, which were recorded in all the amendment areas of the restoration site as well as unprotected site. *Dichanthium annulatum* was

Table 6: Grass and Herbaceous Species in and around Dhordo Restoration site

S. No	Species	Species Recorded in				
		Restoration Site	Restoration Site		Out side Area	*Prosopis* area
			Unploughed	Ploughed		
1	*Ahstida funiculata*	+	+	+	+	+
2	*Aeluropus logopoides*	+	+	+	+	+
3	*Cenchrus ciliaris*	+	+	+	-	-
4	*Cenchrus setigerus*	+	+	+	+	+
5	*Chlohs barbata*	+	+	+	+	+
6	*Cyperus rotundus*	+	+	+	+	+
7	*Cyperus haspan*	+	+	+	-	-
8	*Chrysopogan fulvus*	+	+	+	-	-
9	*Dactyloctenium aegyptium*	+	+	+	+	+
10	*Dichanthium annulatum*	+	+	+	+	+
11	*Digera muricata*	+	+	+	+	+
12	*Dinebra retroflexa*	+	+	+	+	+
13	*Eragrostis tenella*	+	+	+	+	+
14	*Eragrostis* sp.	+	+	+	+	-
15	*Echinocloa* sp.	+	+	+	+	+
16	*Gandhiro**	+	+	+	+	+
17	*Setaha pallide*	+	+	+	-	-
18	*Setaha* sp.	+	+	+	+	+
19	*Sporobolus helvolus*	+	+	+	+	+
20	*Sporobolus pallidus*	+	+	+	-	-
21	*Scirpus* sp.	+	+	-	-	-
22	*Tetrapogan tenellus*	+	+	+	+	+
23	*Tragus* sp.	+	+	+	+	+
24	*Themeda triandra*	+	+	-	-	-
25	*Cressa cretica*	+	+	+	+	+
Total species		*25*	*25*	*23*	*18*	*17*
% Occurrence		*100.0*	*100.0*	*92.0*	*72.0*	*68.0*

** Unidentified species*
The list details the occurrence of species in the three sites. Some of the above mentioned species were not recorded in the sampling quadrates.

seen only on vertical slopes while the occurrence of *Chrysopogan fulvus* and *Setaria* sp. were restricted only to the unploughed area (**Table** 7) of the restoration site.

5.3. SPECIES DISTRIBUTION PATTERN

Plant distribution in an area is not homogenous. In nature, species that produce large number of wind dispersed seeds get scattered uniformly all over the area and on germination the plants grow throughout, while seeds of those species which do not have such dispersal mechanism, are generally shed near the plants or they are dispersed by animals or by other means. Such species are not scattered uniformly all over the area and their occurrence is restricted to aggregation or in patches. The distribution pattern of species in an area can be obtained through percentage frequency estimation. Raunkaier (1934) classified five broad categories of distribution based on the percentage frequency of species. This classification was used to evaluate the distribution pattern of different grass species present in and around the study sites. Raunkaier's frequency classes are as follows:

Class A: Species with frequency from 1-20 per cent Class B: Species with frequency from 21- 40 per cent Class C: Species with frequency from 41- 60 per cent Class D: Species with frequency from 61-80 per cent Class E: Species with frequency from 81-100 per cent.

Table 7: Grass and Herbaceous Species at Bhirandiyara Site

S. No	Species	Species Recorded in						
		Restoration Site	Under Different Amendment*					Unprotected Area
			Unploughed	Ploughed	Broad Slope*	Vertical Slopes	Horizontal Slopes	
1	*Cyperus haspan*	1	+	+	+	+	+	+
2	*Sporobolus helvolus*	1	+	+	+	+	+	+
3	*Dichanthium annulatum*	1	-	-	-	+	-	-
4	*Aeluropus logopoides*	1	+	+	+	+	+	+
5	*Echinocloa* sp.	1	+	+	+	-	-	-
6	*Cenchrus setigerus*	1	+	+	+	+	+	-
7	*Chrysopogon fulvus*	1	+	-	-	-	-	-
8	*Cyperus rotundus*	1	+	+	+	+	+	+
9	*Scirpus* sp.	1	+	+	+	+	+	+
10	*Pennisetum pedicellatum*	1	+	-	-	+	+	-
11	*Setaria* sp.	1	+	-	-	-	-	-
12	Cressa *cretica*	1	+	+	+	+	+	+
Total species		12	11	8	8	9	8	6
% Occurrence		100.0	91.7	66.7	66.7	75.0	66.7	50.0

Unidentified species

In this classification it is presumed that the class E and D reflects high to moderate uniform distribution, class C and B showed high to moderate random distribution while class A reflects aggregation of species.

5.3.1. Species Distribution Pattern at Dhordo

At Dhordo restoration site, of the 12 important selected species **(Table** 8), *Cyperus rotundas* and Cressa *cretica* fall under class D and surprisingly no species were recorded under Class E. The species such as *Chloris barbata, Sporobolus sp.* and *Eragrostis* sp. fall under class B while a maximum of 8 species (67 per cent); *Setaria sp., Aeluropus logopoides;* Gandhiro, *Echinocloa* sp., *Cenchrus* sp., *Dactyloctenium aegyptium, Tetrapogan tenellus* and *Dichanthium annulatum* were registered under class A.

Table 8 also highlights that, there was a slight variation in the distribution of certain species during the period between September (beginning of study) and November (end of study). During the course of the post monsoon, the distribution of species such as *Chloris barbata* shifted from class A to B, *Sporobolus* sp. from A to C, *Cressa cretica* from C to D, *Aeluropus logopoides* from A to B and *Cenchrus* sp. from A to B while only one species, *Cyperus rotundas* showed a reverse trend from D to C **(Table** 8). However, among all, *Sporobolus* sp. showed a maximum increase in its distribution range during the study period while there was not much variation in the distribution of other species. The relationship between different frequency classes (class A- 9, B-1, C-1, D-1 and E-0) enunciated during September are A>B=C=D>E and, in November the trend was (class A-6, B-4, C-2, D-1 and E-0) A>B>C>D>E. Thus, at the beginning and at the end of the study period, the value of E was lower than D in the Dhordo restoration site.

From the **Table 9** it is clear that, certain species have distributional variation under different soil amendments in Dhordo. The species such as *Cyperus rotundus, Chloris barbata, Cressa erotica* and *Cenchrus* sp. showed more distribution in the ploughed area than in unploughed area. *Eragrostis sp.* is the only species which had healthier distribution in unploughed area while species like *Sporobolus* sp., *Setaria sp., Aeluropus logopoides,* Gandhiro, *Echinocloa* sp., *Dichanthium annulatum, Dactyloctenium aegyptium* and *Tetrapogan tenellus* registered no changes in their distribution class under ploughed and unploughed conditions. The frequency relationship established shows that, (class A-9, B-2, C-1, D-1 and E-0)

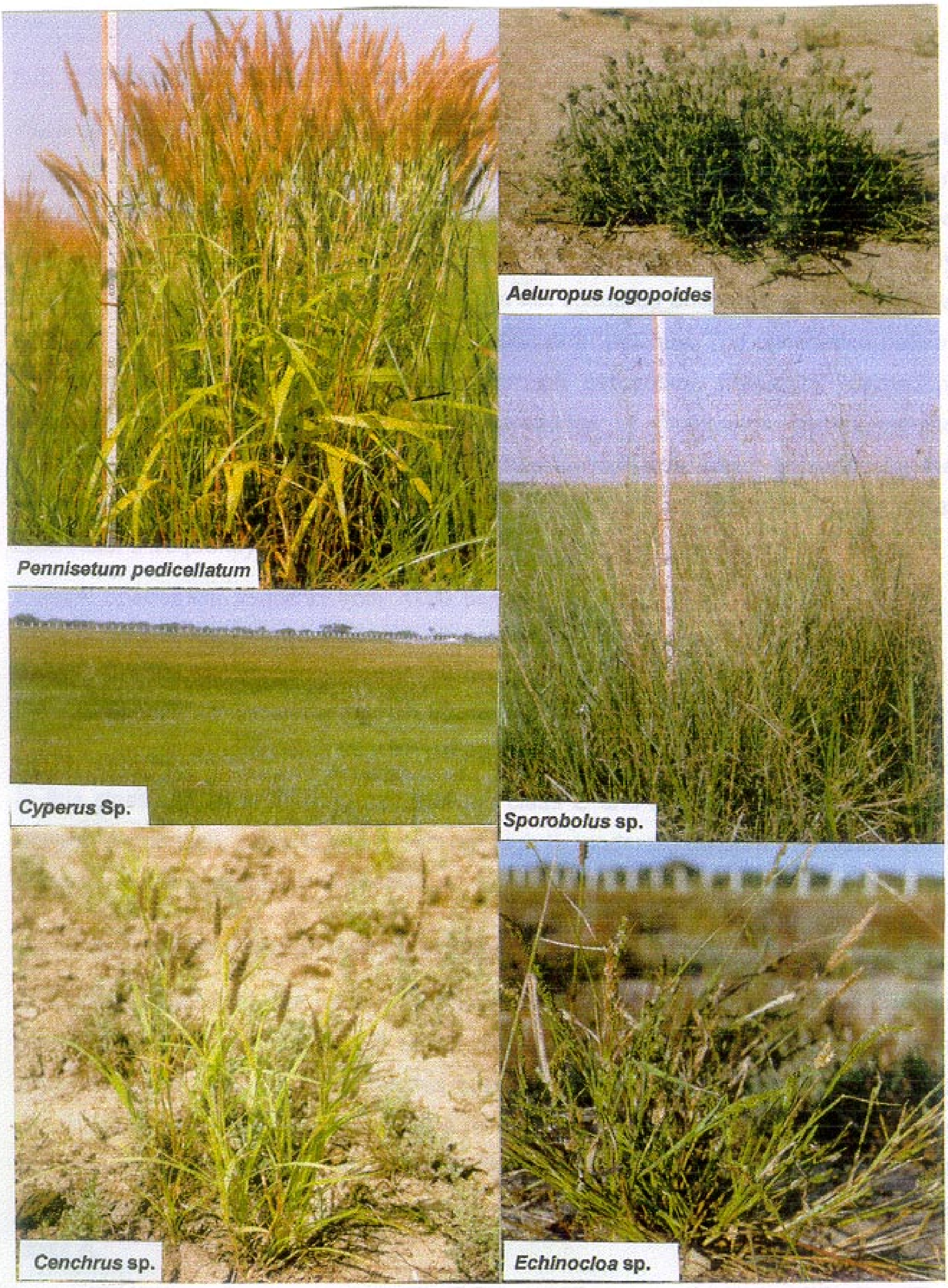


Figure 10: few Important Grass Species recorded in the Restoration Sites

Table 8: Frequency Occurrence / Distribution Pattern of Plant Species at Dhordo

Species	September (n= 108)		November (n =70)		Over All i	n = 428)
	No / % Frequency	Distribution Class	N /% Frequency	Distribution Class	No / % frequency	Distribution Class
Cyperus rotundus	*84 (77.7)*	*D*	*41(58.6)*	*C*	*315(73.6)*	*D*
Chloris barbate	*12(11.1)*	*A*	*20 (28.6)*	*B*	*98 (22.9)*	*B*
Sporobolus sp.	19(17.6)	A	31 (44.3)	C	155(36.2)	B
Setaria sp.	14(12.9)	A	8(11.4)	A	71 (16.6)	A
Cressa *erotica*	*51 (47.2)*	*C*	*48 (68.6)*	*D*	*259 (60.5)*	*D*
Aeluropus logopoides	*5 (4.6)*	*A*	*17(24.3)*	*B*	*67(15.6)*	*A*
Eragrostis sp.	23(21.3)	B	22 (31.4)	B	108(25.2)	B
Gandhiro*	0		6 (8.6)	A	21 (4.9)	A
Echinoctoa sp.	15(13.9)	A	4 (5.7)	A	29 (6.7)	A
Cenchrus sp.	8 (7.4)	A	16(22.9)	B	85(19.9)	A
Dactyloctenium aegyptium	*13(12.0)*	*A*	*4 (5.7)*	*A*	*20 (4.7)*	*A*
Tetrapogan tenellus	*5 (4.6)*	*A*	*3 (4.3)*	*A*	*16(3.7)*	*A*
Dichanthium annulatum	*4 (3.7)*	*A*	*11 (15.7)*	*A*	*45(10.5)*	*A*

*• Frequency is given in parenthesis, * Unidentified.*

Table 9: Frequency Occurrence / Distribution Pattern of Plant Species in Ploughed and Unploughed Area of Dhordo Restoration Site

Species	Un	ploughed (n =258)		Ploughed(n =170)		
	N	% Frequency	Distribution class	N	% Frequency	Distribution class
Cyperus rotundus	*166*	*64.3*	*D*	*149*	*87.6*	*E*
Chloris barbata	*50*	*19.4*	*A*	*48*	*28.2*	*B*
Sporobolus sp.	90	34.9	B	65	38.4	B
Setaria sp.	48	18.6	A	23	13.5	A
Cressa erotica	*149*	*57.7*	*C*	*110*	*64.7*	*D*
Aeluropus logopoides	*35*	*13.6*	*A*	*32*	*18.8*	*A*
Eragrostis sp.	81	31.4	B	27	15.9	A
Gandhiro*	15	4.8	A	6	3.5	A
Echinocloa sp.	17	6.6	A	12	7.1	A
Cenchrus sp.	30	11.7	A	55	32.4	B
Dactyloctenium aegyptium	*16*	*6.2*	*A*	*4*	*2.4*	*A*
Tetrapogan tenellus	*10*	*3.9*	*A*	*6*	*3.5*	*A*
Dichanthium annulatum	*27*	*10.5*	*A*	*18*	*10.6*	*A*

Unidentified

Table 10: Frequency Occurrence / Distribution Pattern of Plant Species in Unprotected and *Prosopis juli flora* Infested Areas of Dhordo

Species	Unprotected Area			*Prosopis juli flora* Infested Area		
	N	Frequency	Distribution Class	N	Frequency	Distribution Class
Cyperus rotundus	*34*	*70.8*	*D*	*15*	*38.5*	*B*
Chloris barbata	*20*	*41.7*	*C*	*14*	*35.9*	*B*
Sporobolus sp.	10	20.8	B	3	7.7	A
Setaria sp.	*0*	*0.0*		*4*	*10.3*	*A*
Cressa cretica	*36*	*75.0*	*D*	*14*	*35.9*	*B*
Aeluropus logopoides	*19*	*39.6*	*B*	*5*	*12.8*	*A*
Eragrostis sp.	*6*	*12.5*	*A*	*7*	*17.9*	*A*
Gandhiro	*0*	*0.0*	-	*4*	*10.3*	*A*
Echinocloa sp.	0	0.0	-	1	2.6	A
Cenchrus sp.	0	0.0	-	0	0.0	-
Dactyloctenium aegyptium	*0*	*0.0*	-	*0*	*0.0*	-
Tetrapogan tenellus	*0*	*0.0*	-	*0*	*0.0*	-
Dichanthium annulatum	*1*	*2.1*	*A*	*0*	*0.0*	-

A>B>C=D>E in the unploughed area while (class A-8, B-3, C-0, D-1 and E-1) it was A>B>C<D=E in the ploughed area. The former had a lower value of E than D while the latter reflects equal.

At site B, the species like *Cyperus rotundus* and *Cressa cretica* fall under class D *Chloris barbata* under class C while *Sporobolus* and *Aeluropus logopoides* under class B, *Eragrostis sp.* and *Dichanthium annulatum* under class A. Contrary to this, ir *Prosopis juliflora* infested area, all the recorded species fall under either class A or B and surprisingly no species were recorded under Class C, D and E. Thus, the species distribution in this area was either aggregated or patchy in nature **(Table 10).** The frequency relationship established shows that, (class A-2, B-2, C-1, D-2 and E-0) A=B>C<D>E in the unprotected area (site B) while (class A-6, B-3, C-0, D-0 and E-0) it was A>B>C=D=E in *Prosopis juliflora* infested areas.

5.3.2. Species Distribution Pattern at Bhirandiyara

The percentage frequency of various plant species indicated that *Cyperus haspan* (81.5 per cent) and *Cressa cretica* fall under class E and thus showed a more uniform distribution while *Aeluropus logopoides* and *Scirpus* sp. exercised a random distribution (class B). The rest of the species fall under class A and thereby showed aggregation in nature. Looking at the variation in the distribution pattern between October and December, species like *Cyperus haspan* and *Scirpus* sp. showed a reverse trend. The former had shifted from E to D and the latter from C to A. Thus the distribution of the latter was very much narrowed during the course of the post monsoon while Cressa *cretica* is the only species which showed a positive trend from high random (class C) to high uniform (class E) distribution.

The species such as *Cenchrus* sp., *Eragrostis sp.* and *Dichanthium annulatum* were totally absent during the initiation of the study (October). However, they appeared in the restoration site during the course of post monsoon while *Sporobolus* sp. and *Echinocloa* sp., showed no changes in their distribution pattern during the study period **(Table** 11). The frequency relationship showed that, (class A-3, B-0, C-1.D-0 and E-1) A>B<C>D<E during October while it was (class A-5, B-1, C-0,D-1 and E-1) A>B>C<D=E during December.

The two species, *Cyperus haspan* and *Cressa cretica* fall under class E (uniform distribution) in various amendments of the restoration site, i.e. unploughed, ploughed, broad slopes, and unprotected area while both were in class D in narrow horizontal slopes and class C and D respectively in narrow vertical slopes. *Aeluropus logopoides* was randomly distributed (class B, C)

Table 11: Frequency and Relative Frequency of Species in Bhirandiyara

Species	October (n = 40)	% Frequency / Distribution Class	December (n = 40)	% Frequency/ Distribution class	Overall Average	
					N=200	% Frequency / Distribution Class
C. *haspan*	*36*	*90.0 / E*	*27*	*67.5 / D*	*163*	*81.5/E*
Sporobolus sp.	4	10.0 /A	6	15.0/A	34	17.0/A
Cressa sp.	24	60.0 / C	39	97.5 / E	164	82.0 / E
Aeluropus sp.	6	15.0/A	12	30.0 / B	62	31.0/B
Eragrostis sp.	*0*	*0.0*	*1*	*2.5 /A*	*1*	*0.5/A*
Echinocloa sp.	4	10.0/A	6	15.0/A	27	13.5/A
Cenchrus sp.	0	0.0	1	2.5/A	3	1.5/A
Dichanthium sp.	0	0.0	0	0.0	3	1.5/A
Scirpus sp.	18	45.0 / C	8	20.0 / A	55	22.5 / B

** Distribution class are presented from /A to /E*

Table 12: Relative Frequency of Species in Different Amendments at Bhirandiyara

Species	Unploughed Area (n =40)		Ploughed Area (n=40)		Broad Slopes (n=40)		Vertical Slopes (n =40)		Horizontal Slopes (n =40)		Outside Restoration Site (n =36)	
	N	Fre./ Class	n	Fre./ Class	N	Fre./ Class	n	Fre./ Class	n	Fre./Class	n	Fre./ Class
C. *haspan*	*40*	*100/E*	*40*	*100/E*	*30*	*75/D*	*21*	*52.5 /C*	*32*	*80/D*	*36*	*100.0/E*
Sporobolus	*7*	*17.5/A*	*8*	*20/A*	*2*	*5/A*	*14*	*35/B*	*3*	*7.5/A*	*0*	
Cressa	*36*	*90/E*	*35*	*87.5 / E*	*35*	*87.5/ E*	*27*	*67.5/ D*	*31*	*77.5 /D*	*35*	*97.2 / E*
Aeluropus	*14*	*35 /B*	*6*	*15/A*	*13*	*32.5 /B*	*20*	*50/C*	*9*	*22.5 /B*	*3*	*8.3/A*
Echinocloa	*8*	*20/A*	*4*	*10/A*	*2*	*5/A*	*7*	*17.5/A*	*6*	*15/A*	*0*	*0*
Cenchrus	*0*	*0*	*0*	*0*	*1*	*2.5/A*	*1*	*2.5/A*	*1*	*2.5/A*	*0*	*0*
Dichanthium	*0*	*0*	*0*	*0*	*2*	*5/A*	*1*	*2.5/A*	*0*	*0*	*0*	*0*
Scirpus	*16*	*40/B*	*14*	*35/B*	*4*	*10/A*	*4*	*10/A*	*17*	*42.5/ C*	*3*	*8.3 / A*

** Fre. Frequency, Class- A to E : Distribution Class.*

in all the three categories of slopes and unploughed area, while it showed aggregation in other areas. *Sporobolus* sp. aggregations were found in all the amendments and outside except in vertical slopes where it showed class B while *Cenchrus* sp. showed aggregation in all the slopes **(Table 12).**

The frequency relationship established for unploughed area was (class A-2, B-2, C-0, D-0 and E-2) A=B>C=D<E, the same was (class A-3, B-1, C-0, D-0 and E-2) A>B>C=D<E in the ploughed area, (class A-5, B-1, C-0, D-1 and E-2) A>B>C<D<E in broad slopes, while it showed a variation of (class A-4, B-1, C-2, D-1 and E-0) A>B<C>D>E in narrow vertical slopes and (class A-3, B-1, C-1, D-2 and E-0) A>B=C<D>E in narrow horizontal slopes. The former three amendments highlight higher values of E than D while the latter two amendments showed a reverse trend, lower E value than D. The unprotected area showed (class A-2, B-0, C-0, D-0 and E-2) A>B=C=D<E, higher value of E than D.

Table 13: Dominance Index of Plant Species at Dhordo

S. No	Species	Restoration Site		Unprotected Area	*Prosopis juliflora* Area
		Unploughed	Ploughed		
1	*Cyperus rotundus*	*0.004*	*0.01*	*0.08*	*0.05*
2	*Chloris barbata*	*0.006*	*0.04*	*0.03*	*0.04*
3	*Sporobolus* sp.	0.114	0.07	0.02	0.001
4	*Setaria sp.*	*0.006*	*0.003*	*0.004*	*0.02*
5	*Aeluropus logopoides*	*0.001*	*0.002*	*0.05*	*0.02*
6	*Eragrostis sp.*	*0.008*	*0.002*	*0.003*	*0.02*
7	*Gandhiro**	*0.001*	*0.0007*	*0.0004*	*0.01*
8	*Echinocloa* sp.	0.002	0.0009	0.0003	0
9	*Cenchrus* sp.	0.009	0.02	0	0.00002
10	*Dactyloctenium aegyptium*	*0.0002*	*0.0001*	*0*	*0.000985*
11	*Tetrapogan tenellus*	*0.0002*	*0.0003*	*0*	*0.00013*
12	*Dichanthium annulatum*	*0.013*	*0.005*	*0.002*	*0.00001*

Unidentified

5.4 SPECIES DOMINANCE

The species, which exert major controlling influence on the community by virtue of their size, numbers, production are called dominant. Simpson (1949) has devised a formula for estimating the Index of Dominance ($C = E (ni / N)^2$) based on the biomass value of species, that highlights the importance of each species in relation to the community as a whole.

5.4.1 Species Dominance at Dhordo

Sporobolus sp. forms the dominant species in both ploughed and unploughed areas of the Dhordo restoration site while at site B and C, *Cyperus rotundus* was the dominant. The dominance index of seven species; *Cyperus rotundus*, *Chloris barbata*, *Aeluropus logopoides*, Gandhiro, *Echinocloa sp.*, *Cenchrus* sp. and *Tetrapogan tenellus* was comparatively higher in the ploughed area than the unploughed area. At site B, *Aeluropus logopoides* forms the second dominant and was followed by *Chloris barbata* and *Sporobolus* sp. At site C, the second dominant species was *Chloris barbata* while *Sporobolus* sp. and *Cenchrus* sp. forms the less and least dominant' species respectively **(Table 13).**

5.4.2 Species Dominance at Bhirandiyara

In Bhirandiyara, *Cyperus haspan* forms the dominant species in all the amendments and unprotected area except in narrow vertical slopes where *Aeluropus logopoides* exerted domination. *Sporobolus* sp. was found to be second dominant in ploughed and broad slopes whereas it was third dominant in narrow vertical and horizontal slopes **(Table** 14). *Cenchrus* sp. was least dominant in unploughed and narrow horizontal slopes but, totally absent in ploughed and unprotected area.

Table 14: Dominance Index of Plant Species at Bhirandiyara

S. *No*	*Species*	*Unploughed*	*Ploughed*	*Slope Broad*	*Slope Vertical*	*Slope Horizontal*	*Outside*
1	*Cyperus haspan*	*0.38*	*0.5*	*0.49*	*0.08*	*0.38*	*0.97*
2	*Sporobolus* sp.	0.005	0.01	0.008	0.05	0.007	0
3	*Aeluropus logopoides*	*0.038*	*0.004*	*0.008*	*0.14*	*0.04*	*0.0001*
4	*Echinocloa* sp.	0.003	0.0005	0.0001	0.002	0.0006	0
5	*Cenchrus* sp.	0.0006	0	0.003	0.004	0.0004	0
6	*Scirpus* sp.	0.001	0.007	0.003	0.0002	0.003	1.93E-06

5.5 SPECIES ASSOCIATION

In a community of plants several species grow near each other. Interspecific association between two species was evaluated through association index. The association index estimated for different species was broadly classified into four classes; low (0 - 0.25), moderate (0.26 - 0.50), high (0.51 - 0.75) and very high (above 0.76) associations.

At Dhordo, totally six important species; *Cyperus rotundas, Sporobolus* sp., *Aeluropus logopoides, Dichanthium annulatum, Cenchrus* sp. and *Cressa cretica* were selected for evaluating the association index. Of which, *Cyperus rotundus* showed a higher association with *Cressa cretica* and moderate association with *Sporobolus* sp. and low association with all other species. *Sporobolus* sp. exercised very high association with *Cyperus rotundus* and *Cressa cretica* whereas *Chloris barbata, Aeluropus logopoides, Cressa cretica* and *Cenchrus* sp. also showed moderate association. Interestingly, except *Chloris barbata,* all these species have low association with *Dichanthium annulatum*. Apart from this, *Dichanthium annulatum* and *Aeluropus logopoides* exerted high association with *Sporobolus* sp. **(Table 15).**

In Bhirandiyara, due to low species diversity, totally four common species were selected for evaluating the association index. These species includes; *Cyperus haspan, Sporobolus* sp., Cressa *cretica* and *Aeluropus logopoides*. Of which, *Cyperus haspan* and Cressa *cretica* showed low association whereas *Sporobolus* sp. reflects high association with all these species and *Aeluropus logopoides* exercised high association with *Cyperus haspan* and *Cressa erotica* **(Table 16).**

Table 15: Association Index of Dhordo Restoration Site

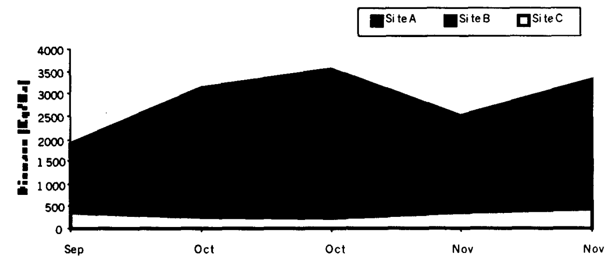
Species Association	*Index*	*Species Association*	*Index*	*Species Association*	*Index*
Cyperus – Cressa	*0.54*	*Cressa - Cyperus*	*0.65*	*Cenchrus - Cyperus*	*0.66*
Cyperus – Sporobolus	*0.34*	*Cressa - Sporobolus*	*0.37*	*Cenchrus - Cressa*	*0.52*
Cyperus – Chloris	*0.22*	*Cressa - Chloris*	*0.25*	*Cenchrus - Sporobolus*	*0.44*
Cyperus – Aeluropus	*0.16*	*Cressa - Aeluropus*	*0.17*	*Cenchrus - Chloris*	*0.39*
Cyperus – Cenchrus	*0.18*	*Cressa - Cenchrus*	*0.17*	*Cenchrus - Aeluropus*	*0.24*
Cyperus – Dichanthium	*0.09*	*Cressa - Dichanthium*	*0.12*	*Cenchrus - Dichanthium*	*0.11*
Sporobolus – Cyperus	*0.92*	*Dichanthium - Cressa*	*0.67*	*Chloris – Cyperus*	*0.70*
Sporobolus – Cressa	*0.84*	*Dichanthium - Cyperus*	*0.62*	*Chloris – Cressa*	*0.66*
Sporobolus – Chloris	*0.36*	*Dichanthium -*	*0.60*	*Chloris – Sporobolus*	*0.41*
Sporobolus – Cenchrus	*0.32*	*Dichanthium - Chloris*	*0.33*	*Chloris – Cenchrus*	*0.34*
	0.30	*Dichanthium - Cenchrus*	*0.20*	*Chloris – Aeluropus*	*0.27*
Sporobolus – Dichanthium	*0.23*	*Dichanthium - Aeluropus*	*0.18*	*Chloris – Dichanthium*	*0.15*
Aeluropus – Cyperus	*0.75*	*Association Index*		*Range*	
Aeluropus – Cressa	*0.66*				
Aeluropus – Sporobolus	*0.52*	*Low*		*0-0.25*	
Aeluropus – Chloris	*0.39*	*Moderate*		*0.26-0.5.*	
Aeluropus – Cenchrus	*0.29*	*High*		*0.51-0.75*	
Aeluropus – Dichanthium	*0.11*	*Very High*		*Above 0.76*	

Table 16: Association Index of Bhirandiyara Restoration Site

Species Association	Index	Species Association	Index	Species Association	Index
Cyperus – Cressa	0.24	*Cressa - Cyperus*	0.24	*Sporobolus* -Cressa	0.62
Cyperus- Sporobolus	0.12	*Cressa - Sporobolus*	0.13	*Sporobolus - Cyperus*	0.59
Cyperus- Aeluropus	0.19	*Cressa - Aeluropus*	0.20	*Sporobolus - Aeluropus*	0.53
Aeluropus - Cyperus	0.52	*Association Index*			
Aeluropus - Cressa	0.53				
Aeluropus - Sporobolus	0.29	*Very High above 0.76, High 0.51-0.75, Moderate 0.26 - 0.50, Low Up to 0.25.*			

5.6 BIOMASS

Figure 11: Biomass Production at Three Sites of Dhordo



Along with the grassland restoration programme in the Banni area, GUIDE has also carried out a monitoring study on the biomass production of different grass species under restored and unprotected conditions. The results obtained during the course of this study are expected.

to provide suitable strategies for bringing out the scope of sustainable utilisation of Banni grassland resources. The results obtained from Dhordo and Bhirandiyara during the year 1996-1997 are summarised as below.

5.6.1 Biomass Production in Dhordo site

At Dhordo, data on biomass was collected from three sites; site A, site B and site C. It is presumed that, collection of biomass data on grass species at these three sites would help in evaluating the biomass generation under different situations, i.e. grassland restoration, grazing and shrub / tree cover of *Prosopisjuli flora.*

During the month of September 1997 (mid monsoon), there was sufficient moisture availability and a concurrent reduction in surface soil salinity which favoured vegetative growth of grasses in many areas of Banni. The biomass obtained even during this month at site C was 43.8 and 81.7 per cent lower than site B and site A respectively **(Table** 17).

Among the five sampling carried out between September and November 1997, maximum biomass obtained at site A, B and C was 3546.9 kg/ha in second fortnight of October (mid study period), 618.3 kg/ha in September (beginning of study) and 410 kg/ha during end of November (end of study) respectively **(Figure** 11).

During the study period, the biomass increased by 73.3 per cent at site A and 17.9 per cent at site C whereas it decreased by 32.1 per cent at site B **(Table 17** and **Figure** 12).

Further, **Table** 17 also revealed that, removal of grazing pressure (by trench fencing) and competition (uprooting of weed trees / shrubs) in the restoration site enabled the grass to grow more vigorously. The biomass data at the restoration site in the beginning (September 1997) and at the end of the study period (November 1997) highlights that, the production was 3 to 7.8 times higher than site B and 5.5 to 8 times higher than site C respectively **(Table 17).**

5.6.1.1 Biomass under Different Soil Amendments at Site A

It was also noted that, unploughed and ploughed area showed variation in the productivity of grass species. Interestingly, the biomass recorded was higher in the unploughed areas than in ploughed areas **(Table 18** and **Figure 13).** However, the monthly increase in the productivity recorded was high in the ploughed area. Between September (1511.9 kg/ha) and November (2736.9 kg/ha) the biomass increased by 81 per cent in the ploughed area while it increased by 67 per cent (2177.8 to

Table 17: Biomass production (Kg / Ha) in and around Dhordo Restoration Site

S. No	Site details	Sep. '97	Oct. '97	Oct. '97	Nov. '97	Nov. '97	Between Sep. & Nov. (%+/-)
1	Restoration Site (Site A)	1899.3	3120.5	3546.9	2504.1	3291.5	73.3
2	Unrestored Area (Site B)	618.3	347.0	83.5	241.5	420.0	-32.1
3	*Prosopis* Area (Site C)	347.6	276.9	215.7	324.7	410.0	17.9

Table 18: Biomass (Kg / Ha) in Dhordo (ploughed and unploughed) Restoration Site

Months	Dhordo Restoration Plot (ploughed)	Dhordo Restoration Plot (unploughed)	% Difference (Between ploughed and unploughed)
September	1511.9	2177.8	44.0
October	2764.4	3298.5	19.3'
October	3590.4	3519.7	-1.9
November	1965.3	2932.3	49.2
November	2736.9	3639.8	32.9

3639.8 kg/ha) in unploughed area.

5.6.1.2 Productivity of Different Grass Species in Dhordo

There was a considerable variation in the productivity of different grass species in the three sites of Dhordo. In total 12 important as well as commonly available grass species *(Cyperus rotundus, Chlohs barbata, Sporobolus* sp., *Setaria sp., Aeluropus logopoides, Eragrostis sp.,* Gandhiro, *Echinocloa* sp., *Cenchrus* sp., *Dactyloctenium aegyptium, Tetrapogan tenellus* and *Dichanthium annulatum)* were selected for the analysis **(Table 19** and **Figure** 14). The total biomass estimated for these 12 species at three sites varied from 2505 kg/ha at site A, which decreased to 230.3 kg/ha at site B and 201.9 kg/ha at site C. The biomass recorded at site C was 12.3 per cent lesser than site B. The 12 species encompasses 87.2 per cent of the biomass estimated at site A, 67.3 per cent at site B and 64.1 per cent at site C. The biomass of few highly palatable species such as *Sporobolus* sp.,

Figure 13 : Biomass Production Under Different Soil Amendments in Dhordo Restoration Site

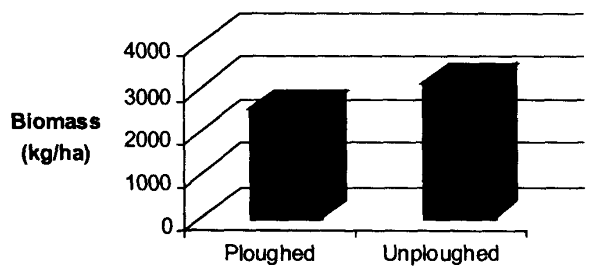
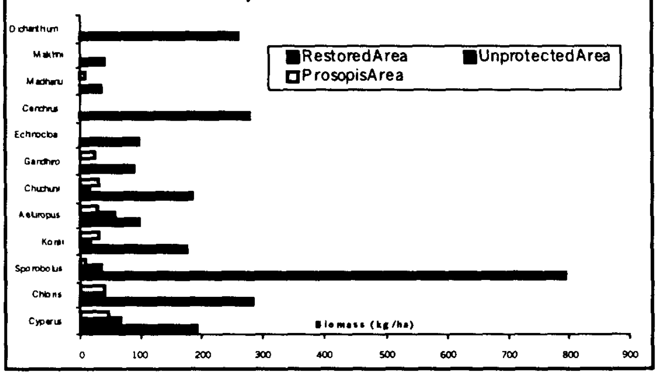


Figure 14: Average Biomass of Few Selected Species at Dhordo



Cenchrus sp. and *Dichanthium annulatum* encompasses 31.7,11.1 and 10.3 per cent respectively at site A, whereas it decreased to 14.5, 0.0 and 1.3 per cent respectively at site B and 3.6, 0.004 and 0.3 per cent respectively at site C. Contrary to this, the biomass contribution of species like *Cyperus rotundus, Aeluropus logopoides* and *Chloris barbata* which are comparatively less palatable at matured stage, was least at site A; 7.6, 3.8 and 11.2 per cent respectively while it was 27.9, 23.3 and 16.7 at site B and 21.6, 12.2 and 19.2 at site C.

A comparison of grass species between site A and B shows that except *Aeluropus logopoides*, which showed a lesser decrease (-44.1 per cent) at site B, all other species decreased significantly (66.2 to 100 per cent). Three highly palatable grass species such as *Cenchrus*, *Dactyloctenium aegyptium* and *Tetrapogan tenellus* were totally absent at site B, while only *Echinocloa* sp. was absent at site C. Further, a comparison between site B and C showed that the biomass of grass species such as Gandhiro (363 per cent), *Eragrostis sp.* (119.7 per cent), and *Setaria sp.* (79.1 per cent) were found more at site C than at B. Among the decreasers (highly palatable) of site C, maximum decrease was recorded in *Sporobolus* sp. (78.4 per cent) and *Dichanthium annulatum* (75.9 per cent) (Table 19).

Between September and November, total biomass of these selected 12 species showed an increase of 75.6 per cent at site A, whereas it decreased to 44.7 per cent at site B and 40.1 per cent at site C **(Table 20).** The comparison of biomass of grass species between September and November at site A shows that, except three species; *Cyperus rotundus*, *Setaria sp.* and *Dactyloctenium aegyptium*, all other species showed an increase. Among the species at site A, maximum increase was recorded on *Sporobolus* sp., which alone encompasses **22** per cent of the biomass in September to 36 per cent in

Table 19: Average Biomass (kg/ha) of Selected Species at Three Sites of Dhordo

S. No	Species	Dhordo Restoration plot	Degraded Area	% Difference (Restoration Plot and Degraded Area)	*Prosopis jull flora* Area	% Difference (Restoration Plot and *Prosopis* Area)	% Difference (Degraded Area and *Prosopis Area)*
1	*Cyperus* sp.	189.7(7.6)	64.2 (27.9)	-66.2	43.6(21.6)	-77.0	-32.5
2	*Chloris barbata*	*280.4(11.2)*	*38.5(16.7)*	*-86.3*	*38.8(19.2)*	*-86.2*	*-0.8*
3	*Sporobolus* sp.	794.9(31.7)	33.4(14.5)	-95.8	7.2 (3.6)	-99.0	-78.4
4	*Setaria sp.*	*172.9*	*15.3*	*-91.2*	*27.4*	*-84.2*	*,79.1*
5	*Aeluropus* sp.	95.9 (3.8)	53.6 (23.3)	-44.1	24.7(12.2)	-74.2	-53.9
6	*Eragrostis sp.*	*184.5*	*13.2*	*-92.8*	*29.0*	*-92.8*	*119.7*
7	*Gandhiro*	*86.3*	*4.6*	*-94.7*	*21.3*	*-75.3*	*363.0*
8	*Echinocloa* sp.	95.2	4.2	-95.6	0	-100.0	-100.0
9	*Cenchrus sp.*	*277.4(11.1)*	*0*	*-100.0*	*0.91 (0.004)*	*-99.7*	*100.0*
10	*Dactyloctenium sp.*	*31.1*	*0*	*-100.0*	*5.9*	*-81.0*	*100.0*
11	*Tetrapogan* sp.	39.6	0	-100.0	2.4	-93.9	100.0
12	*Dichanthium*	*257.1 (10.3)*	*2.9(1.3)*	*-98.9*	*0.7 (0.3)*	*-99.7*	*-75.9*
Total Biomass		*583.8*	*53.9*	*-90.8*	*9.606*	*-91.9*	*-12.3*

** Percentage are given in parenthesis*

Table 20: Biomass (kg/ha) Productivity of Different Species at Three sites of Dhordo

s. No	Species	Dhordo Restoration Site			Degraded Area			*Prosopis juli flora* Area		
		Sep	NOV	%+/-	SEP	NOV	%+/-	SEP	NOV	%+/-
1	*CYPERUS* SP.	250.0 (15.2)	188.9 (6.5)	-24.4	162.4 (32.8)	27.0	-83.4	59.2 (19.9)	62.0 (34.8)	4.7
2	C/I/ORIS *BARBATA*	*97.8 (5.9)*	*283.0 (9.8)*	*189.4*	*60.9 (12.3)*	*52.5 (19.0)*	*-13.8*	*32.6 (10.9)*	*40.67 (22.8)*	*24.8*
3	*SPOROBOLUS* SP.	363.2 (22.0)	1043.0 (36.1)	187.2	79.2 (15.9)	48.0 (17.5)	-39.4	0.0	0.0	0.0
4	*SETARIA SP.*	*225.0 (13.7)*	*88.8 (3.1)*	*-60.5*	*76.2 (15.4)*	*0.0*	*-100.0*	*80.48 (27.1)*	*12.0 (6.7)*	*-85.1*
5	*AELUROPUS* SP.	22.1 (1.3)	192.6 (6.7)	771.1	88.8 (17.9)	128.5 (46.9)	44.7	35.9 (12.1)	24.7 (13.9)	-31.2
6	*ERAGROSTIS SP.*	*243.0 (14.7)*	*250.6 (8.7)*	*8.1*	*1.6 (0.3)*	*18.0 (6.6)*	*1025.0*	*36.4 (12.2)*	*38.7 (21.7)*	*6.3*
7	*GANDHIRO*	*8.7 (0.5)*	*72.8 (2.5)*	*736.8*	*22.8 0*	*0.0*	*~*	*18.4 (6.2)*	*0.0*	*-100.0*
8	*ECHINOCLOA* SP.	54.5 (3.3)	174.0 (6.0)	219.3	0.0	0.0	0.0	0.0	0.0	0.0
9	*CENCHRUS SP.*	*79.3 (4.8)*	*373.7 (12.9)*	*371.2*	*0.0*	*0.0*	*0.0*	*4.6 0*	*0.0*	*-100.0*
10	*DACTYLOCTENIUM SP.*	*135.7 (8.2)*	*2.0 0*	*-88.5*	*0.0*	*0.0*	*0.0*	*29.6 0*	*0.0*	*-100.0*
11	*TETRAPOGAN SP.*	*32.5*	*36.9*	*13.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
12	*DICHANTHIUM SP.*	*135.9 (8.2)*	*186.8 (6.5)*	*37.5*	*3.4 (0.7)*	*0.0*	*~*	*0.0*	*0.0*	*0.0*
TOTAL BIOMASS		*287.7*	*217.2*	*75.6*	*2.7*	*11.4.0*	*-44.7*	*0.0*	*17*	*-40.1*
AVERAGE		*70.6*	*83.8*		*62.5*	*90.0*		*62.3*	*65.1*	

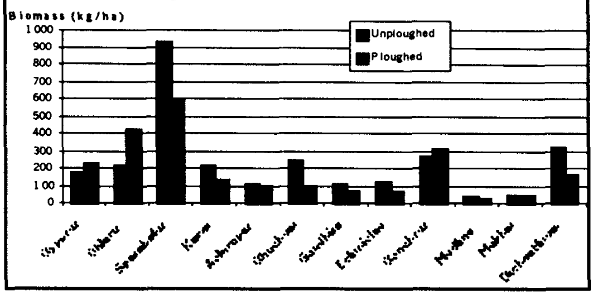
percentage are given in parenthesis

November and is followed by *Cenchrus* sp. (4.8 in September to 12.9 per cent in November) and *Chloris barbata* (5.9 in September to 9.8 per cent in November). These three species alone endowed nearly 32.7 per cent biomass in September, which increased to 58.8 per cent in November **(Table 20).** Though, *Dichanthium annulatum* recorded 37.5 per cent increase during the study period, its biomass contribution for the month of September was 8.2 per cent which, decreased to 6.5 per cent in November. Further, the biomass production of *Dichanthium annulatum* was found far lower than *Sporobolus* sp., which was 62.6 per cent lower in September and 82.1 per cent in November.

At site B, except *Eragrostis sp.* and *Aeluropus logopoides* all other species showed a decrease, while at site C except *Chloris barbata, Cyperus rotundas* and *Eragrostis sp.* all other species showed increasing trend. At site B, the *Aeluropus logopoides* showed an increase of 44.7 per cent during the study period, and contributed 17.8 per cent of biomass in September, which further increased to 46.9 per cent in November. The biomass of highly palatable species such as *Dichanthium annulatum,* Gandhiro was totally grazed out and *Sporobolus* sp. was much reduced at site B and C.

The comparison of biomass of different species between September and November showed that the productivity of species such as *Cenchrus* sp.,

Figure 15: Biomass of Different Species in Unploughed and Ploughed area of Dhordo restoration Site



Chloris barbata, *Echinocloa* sp., and *Dichanthium annulatum* increased tremendously in the ploughed area than the unploughed area **(Table 21** and **Figure** 15).

The increase in productivity of these species was; 221 and 692 per cent for *Cenchrus* sp., 96 and 149 per cent for *Chloris barbata,* 26.5 and 442 per cent for *Echinocloa* sp. and 23 and 60 per cent for *Dichanthium annulatum.* Contrary to this, increase in *Sporobolus* productivity was higher in unploughed area (216 per cent) than in ploughed area (104 percent). **Table 21: Productivity (kg / ha) of Few Grass Species at Dhordo** (under various amendments)

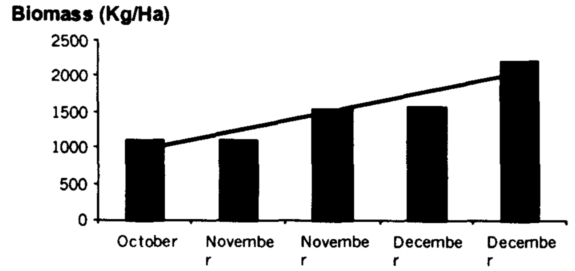
5.6.2 Biomass Productivity at Bhirandiyara Site

The biomass in the restoration site gradually increased from October to December; 1115.9 kg/ha in October to 2228.7 kg/ha in December **(Figure 16)** and thus, showed an increase of 99.7 per cent whereas it decreased to 31.5 per cent in the unprotected area **(Table** 22). Among the five sub-compartments (unploughed, ploughed, broad slope -0.3m height x 5m wide, narrow vertical slope-0.5m height x 3m wide and narrow horizontal slope - 0.5m height x 3m wide) of the restoration site, narrow slopes showed a maximum increase of biomass between October and December; 279.6 per cent in vertical slopes and 171.9 per cent in horizontal slopes. This was followed by unploughed area (112.8 per cent), broad slopes (42.9 per cent) and ploughed area (25.9 per cent). This indicating clearly that the recovery of saline area in narrow steep slopes was faster. The biomass

Table 21: Productivity (kg / ha) of Few Grass Species at Dhordo (under various amendments)

S. No	Species	Unploughed		% Difference	Ploughed		% Difference
		Sep	nov		Sep	nov	
1	*Cyperus* sp.	242.1	211.7	-12.6	261.1	152.7	-41.5
2	*Chloris barbata*	*109.2*	*213.8*	*95.8*	*81.9*	*215.9*	*149.0*
3	*Sporobolus* sp.	424.7	1341.9	216.0	277.8	567.1	104.1
4	*Setaria* sp.	321.6	85.9	-73.3	90.8	93.5	2.9
5	*Aeluropus* sp.	26.1	244.2	835.6	16.6	110.7	566.9
6	*Eragrostis sp.*	*333.3*	*352.4*	*5.7*	*117.5*	*88.6*	*-24.6*
7	*Gandhiro*	*0.0*	*74.8*	*100.0*	*20.8*	*69.6*	*234.6*
8	*Echinocloa* sp.	86.9	109.9	26.5	51.0	276.2	441.6
9	*Cenchrus sp.*	*90.1*	*289.0*	*220.7*	*64.2*	*508.7*	*692.4*
10	*Dactyloctenium* sp.	153.5	3.3	-97.8	111.0	0.0	-100
11	*Tetrapogan* sp.	19.8	50.4	154.5	50.2	15.3	-69.5
12	*Dichanthium* sp.	130.1	159.6	22.7	144.0	230.2	59.9
	Total Biomass	1937.4	3136.9	61.9	1286.9	2328.5	80.9

Figure 16: Biomass Production During Different Months at Bhirandiyara Restoration site



estimated (all grass species) within the restoration site was maximum in the unploughed area in all the months except during the first fortnight of December than the ploughed area. Among the slopes, the broad slopes with a width of 5m had more biomass production except during the end of December than in narrow vertical slopes of 3m width. The biomass of the narrow horizontal slopes was found slightly higher than the narrow vertical slopes during the first fortnight of November and December while in other months it showed low biomass than the vertical slopes **(Table** 22).

A comparison of biomass productivity of unprotected and unploughed protected area of restoration site during the study period shows that the biomass of outside area was comparatively less than the unploughed area of restoration site **(Figure** 17), indicating thereby that to grazing pressure existed in the unrestored area.

From **Table 23** and **24** it was clear that *Cyperus haspan* made a major contribution to the biomass of the area, which was 41.6 per cent of the productivity of restoration site and 82.6 per cent of the unprotected area. Grass species such as *Sporobolus* sp., *Cenchrus* sp., *Aeluropus logopoides*, *Dichanthium annulatum* etc., sown in the area were capable of growing even under low moisture availability whereas *Cyperus haspan* - a water loving species requires high moisture for its survival and growth. Therefore, it was presumed that there will be a change in the contribution of C. *haspan* in various amendment areas during the course of the post monsoon i.e. from October to December. To confirm the above and to understand the recovery process of different sub-compartments of the restoration site, biomass was analysed with and without the contribution of *Cyperus haspan.*

During the month of October, *Cyperus haspan* constituted of more than 67.8 per cent of biomass of the restoration site, which in the month of December decreased to 34.9 per cent **(Table** 24). Further, *Cyperus haspan* was found

almost equal in ploughed (49.8 per cent) and unploughed areas (46.7 per cent) of the restoration site **(Table** 23). However, it decreased to 43.7 per cent in the broader slopes and 38.4 per cent in narrow horizontal slopes and very low contribution of 17.5 per cent was recorded in narrow vertical slopes. The amount of recovery could be clearly visualised

Table 22: Biomass (Kg / Ha) Production at Bhirandiyara (all species)

Site Details	Oct. 97	Nov.	Nov.	Dec.	Dec.97	% +/- (Oct to Dec)
Unploughed	1898.8(34.0)	1353.0	2211.0	2290.0	4040.6 (43.0)	112.8
Ploughed	1343.1 (24.1)	1248.5	1750.0	2355.0	1692.0(18.2)	25.9
Slope Broad	1155.6(9.2)	1249.5	1713.0	845.0	1644.0(17.5)	42.3
Slope Vertical	514.2(11.9)	786.3	1149.5	752.0	1951.5(20.8)	279.6
Slope Horizontal	667.65	916.0	853.2	1625.0	1815.5(19.3)	171.9
Total	5579.3	5553.3	7676.7	7867	9387.6	68.3
Average Biomass in Restoration Site	1349.85	2221.32	3070.68	3146.8	2236.76	-
Outside	0.00	1749.50	787.50	2635.00	1198.50	*-31.5

**data on November and December was compared, Percentage are given in parenthesis*

Table 23: Percentage Contribution of Cyperus haspan in Sub-Compartments of Bhirandiyara Restoration Site

Site Details	All species (Including C. *haspan}*	*Excluding C.haspan*	*% Contribution of C.haspan*
Unploughed	*2358.7*	*471.74*	*46.7*
Ploughed	*1677.7*	*335.54*	*49.8*
Slope Broad	*1321.4*	*264.28*	*43.7*
Slope Vertical	*1030.7*	*206.14*	*17.5*
Slope Horizontal	*1175.5*	*235.1*	*38.4*
Overall	*1512.8*	*883.5*	*41.6*
Outside	*1274.1*	*254.82*	*82.6*

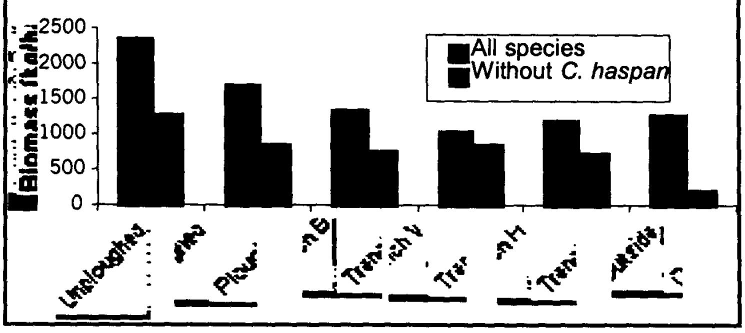
Table 24: Biomass Production at Bhirandiyara Different Months % availability of Cyperus haspan in

Site Details	Oct. 97	*%of C. haspan*	*Nov.97*	*Nov. 97*	*Dec. 97*	*Dec.97*	*%of C. haspan*	*% +/- (Oct to Dec)*
Unploughed	*474.63*	*75.0*	*1176.00*	*1366.50*	*1070.00*	*2197.00*	*45.6*	*164.8*
Ploughed	*513.55*	*61.8*	*689.50*	*747.33*	*1410.00*	*844.50*	*50.1*	*64.4*
Slope Broad	*286.17*	*75.2*	*583.50*	*830.00*	*693.33*	*1325.50*	*19.4*	*363.2*
Slope Vertical	*232.07*	*54.9*	*598.86*	*1064.50*	*642.67*	*1708.00*	*12.5*	*635.9*
Slope Horizontal	*289.55*	*56.6*	*530.50*	*812.74*	*800.00*	*1185.00*	*34.7*	*309.3*
% of C. haspan	*1795.9*	*67.8*				*7260.0*	*34.9*	*304.3*
Outside	*0.00*		*290.50*	*223.43*	*290.00*	*300.57*		*-23.5**

**data of November and December was compared*

by comparing the occurrence of *Cyperus haspan* in various sub-compartments between October and December. The contribution of *Cyperus haspan* decreased from 75 per cent in October to 45.6 per cent in December in the unploughed area while in the unprotected area it decreased from 83.4 to 74.9 per cent. A comparison of data during the same period in other sub-compartments showed that the percentage contribution of *Cyperus haspan* changed from 61.8 to 50.1 at ploughed area, 75.2 to 19.4 at broad slopes, 54.9 to 12.5 at narrow vertical slopes and 56.6 to 34.7 at narrow horizontal slopes **(Table 24).**

Figure 17: Comparision of Biomass With and Without *Cyperus haspan*



% are given in parenthesis Increase in other grass species (excluding *Cyperus haspan)* was recorded maximum at narrow vertical slopes (635.9 per cent), followed by broad slopes (363.2 per cent), narrow horizontal slopes (309.3 per cent), unploughed (164.8 per cent) and ploughed areas (64.4). In contrast to this, the outside area showed a decrease of 23.5 per cent.

Table 25: Average Total Biomass (kg/Ha) Recorded for Few Species at Bhirandiyara

Species	Unploughed	Ploughed	Slopes Broad	Slopes Vertical	Slopes Horizontal	Outside
C. *haspan*	*1172.6(61.9)*	*874.1 (70.9)*	*619.5(70.3)*	*220.5 (27.7)*	*472.2(61.5)*	*1066.3 (98.8)*
Sporobolus sp.	137.0 (7.2)	147.1 (11.9)	77.6 (8.8)	175.1 (22.0)	65.6 (8.5)	0.0
Aeluropus sp.	372.9 (19.7)	79.4 (6.4)	76.5 (8.7)	298.7 (37.6)	153.7 (20.0)	11.7(1.2)
Echinocloa sp.	103.1 (5.4)	27.9 (2.3)	9.7(1.1)	38.0 (4.8)	18.3 (2.4)	0.0
Cenchrus sp.	46.0 (2.4)	0.0	46.3 (5.3)	52.4 (6.6)	14.4(1.9)	0.0
Scirpus sp.	63.5 (3.4)	105.1 (8.5)	52.0 (5.9)	9.9(1.2)	43.7 (5.7)	1.5
Overall	1795.1	122.2	781.5	694.7	667.9	12
Excluding C. *haspan*						
Sporobolus sp.	137.0 (18.9)	147.1 (40.9)	77.6 (29.6)	175.1 (30.5)	65.6 (22.2)	0.0
Aeluropus sp.	372.9(51.6)	79.4 (22.1)	76.5 (29.2)	298.7 (52.0)	153.7(51.9)	11.7(88.6)
Echinocloa sp.	*103.1 (14.3)*	*27.9 (7.8)*	*9.7 (3.7)*	*38.0 (6.6)*	*18.3 (6.2)*	*0.0*
Cenchrus sp.	*46.0 (6.4)*	*0.0*	*46.3 (17.7)*	*52.4(9.1)*	*14.4 (4.9)*	*0.0*
Scirpus sp.	63.5 (8.9)	105.1 (29.2)	52.0(19.8)	9.9(1.7)	43.7 (14.8)	1.5(11.4)
Overall	2477.6	96	989.7	1177.6	901.6	(86.8)
% contribution from Mean biomass	57.5	42.7	35.2	67.5	40.8	

Table 26: Average Biomass in Five Sub-Compartments at Bhirandiyara

Species	Unploughed	Ploughed	Slope Broad	Slope Vertical	Slope Horizontal ,'	Total
Sporobolus sp.	137.0 (22.7)	147.1 (24.4)	77.6(12.9)	175.1 (29.1)	65.6(10.9)	502.4
Aeluropus sp.	372.9 (38.0)	79.4(8.1)	76.5 (7.8)	298.7 (30.4)	153.7 (15.7)	881.2
Echinocloa sp.	103.1 (52.3)	27.9(14.2)	9.7 (4.9)	38.0(19.3)	18.3(9.3)	97
Cenchrus sp.	46.0 (28.9)	0.0	46.3(29.1)	52.4 (32.9)	14.4(9.1)	42
Scirpus sp.	63.5 (23.2)	105.1 (38.3)	52.0(18.9)	9.9 (3.6)	43.7(15.9)	174.3

5.6.2.1 Biomass of Different Grass Species

Apart from *Cyperus haspan*, the biomass of six common grass species of the site *(Sporobolus* sp., *Aeluropus logopoides*, *Echinocloa* sp., *Cenchrus* sp., and *Scirpus so.)* was analysed. Excluding *Cyperus haspan*, the biomass contribution of other five species varied from 67.5 per cent of the mean biomass production of vertical slopes to 35.2 per cent of broad slopes **(Table** 13). Among the five grass species, biomass of *Aeluropus logopoides, a* saline tolerant species was found maximum in all the sub-compartments except in ploughed and broad slope areas. Ploughing and addition of farmyard manure favoured the growth of *Sporobolus* sp., where it contributed 41 per cent of the biomass amongst the five species. In the broad

Table 27: Biomass of Few Selected Species at Bhirandiyara

Species	Unploughed area			Ploughed Area			Outside Area		
	Oct.	Dec.	% +/-	Oct.	Dec.	% +/-	Oct.	Dec.	% +/-
C. *haspan*	*1483.0 (85.5)*	*1843.0 (58.2)*	*24.3*	*829.0 (73.9)*	*847.5 (74.6)*	*2.2*	*1459.0 (100.0)*	*935.5 (99.6)*	*-35.9*
Sporobolus sp.	44.0 (2.5)	301.5 (9.5)	585.2	69.3 (6.2)	68.5	-1.2	0.0	0.0,	-
Aeluropus sp.	68.1 (3.9)	626.5 (19.8)	819.9	47.8 (4.3)	99.0 (8.7)	107.1	0.0	3.5 (0.4)	100.0
Echinocloa sp.	10.0	196.5	1865.0	45.8	0.0	-100.0	0.0	0.0	-
Cenchrus sp.	0.0	230.0	100.0	0.0	0.0	-	0.0	0.0	-
Scirpus sp.	129.0	26.0	-79.8	129.0 (11.5)	120.5 (10.6)	-6.6	0.0	0.0	-
Overall	203.2	1059.2	86.2	206.8	200.2	-1.3	1359	3.1	-35.6
Species	Broad Slope			Vertical Slope			Horizontal Slope		
	Oct	Dec	% +/-	Oct	Dec	% +/-	Oct	Dec	% +/-
C. *haspan*	*905.0 (98.0)*	*318.5 (46.6)*	*-64.8*	*340.0 (75.1)*	*243.5 (16.2)*	*-28.4*	*378.0 (84.7)*	*630.5 (49.6)*	*66.8*
Sporobolus sp.	0.0 (0.0)	148.0 (21.6)	100.0	0.0 (0.0)	645.0 (42.9)	100.0	0.0	172.0 (13.5)	100.0
Aeluropus sp.	12.4 (1.3)	87.5 (12.8)	605.6	21.5 (4.8)	393.5 (26.2)	1730.2	19.6 (4.4)	439.5 (34.6)	2142.3
Echinocloa sp.	5.7	0.0	-100.0	45.5	0.0	-100.0	26.8	28.5	6.3
Cenchrus sp.	0.0	130.0	100.0	45.5	216.5	375.8	21.7	0.0	-100.0
Scirpus sp.	168.0	19.5	-88.4	23.8	3.0	-87.4	147.0	6.5	-95.6

slopes, both *Sporobolus sp.* and *Aeluropus logopoides* were found almost equal. In the unprotected (outside) area, (excluding *Cyperus haspan)* the dominance of *Aeluropus logopoides* was found to be maximum (88.6 per cent of the biomass).

Amongst the five sub-compartments, contribution of *Sporobolus* sp. was maximum in the narrow vertical slopes (29.1 per cent) and was followed by unploughed (22.7 per cent) and ploughed (24.4 per cent) areas. Species like *Aeluropus logopoides* and *Echinocloa* sp. were dominant in unploughed area while *Cenchrus* sp. dominated (32.9 per cent) in the narrow vertical slopes and surprisingly this species was totally absent in the ploughed area. The species *Scirpus* sp. was more in the ploughed area (38.3 per cent) when compared to unploughed area (23.2 per cent).

Between October and December, amongst the six (including *Cyperus haspan)* selected species **(Table** 27), except *Scirpus* sp. all other species showed an increase in the unploughed area. *Sporobolus* sp. was totally absent in the unprotected area while it showed an increasing trend in all the sub-compartments of the restoration site except in ploughed area, where it decreased slightly (1.2 per cent). *Echinocloa* sp. showed a decreasing trend in all the areas except in unploughed and horizontal slope of the restoration site and unprotected area where it was absent. The increase of *Cyperus haspan* during this period was high in narrow horizontal slopes (66.8 per cent) and was followed by unploughed (24.3 per cent) and ploughed (2.2 per cent) areas while it decreased tremendously in broad slopes (64.8 per cent), narrow vertical slopes (28.4 per cent) and outside area (35.9 per cent). *Aeluropus logopoides* was the only species, which showed an increasing trend in all the sub-compartments of restoration site and outside area. The increase was high in horizontal slopes (2142.3 per cent), followed by vertical slope (1730.2 per cent), unploughed (819.9 per cent) and broad slopes (605.6 per cent). *Cenchrus* sp. was another species, which showed an increasing trend in all the sub-compartments of the restoration site except in the ploughed area and unprotected area where it was totally absent.

5.7 BIOMASS OF HERBACEOUS SPECIES - *Cressa cretica*

The herbaceous stratum of restoration site and surrounding area was dominated by Cressa *cretica* commonly known as o/'en. The species had a dense growth with an average height of 12 cm. It has ethnobotanical values such as; useful medicine for reducing cough, respiratory ailments and deworming agent for human as well as livestock (Indhrajee, 1998). This species also increases milk yield as well as the sweetness of milk. Buffalo generally prefers to feed on this herbaceous species.

At Dhordo, percentage contribution of Cressa *cretica* to the mean biomass was very low in the restoration site (7.4 per cent) whereas it increased to 28.7 per cent at site B and 29.7 per cent at site C **(Table 28).** At Bhirandiyara restoration site, Cressa *cretica* contributed about 21.2 per cent of the biomass. Among the sub-compartments, the unploughed area had the lowest biomass contribution of Cressa *cretica* (4.4 per cent) and was followed by vertical slope (20.4). In the other sub-compartments, it contributed more than 25 per cent to the total biomass, with a maximum contribution of 34.7 per cent in horizontal slopes. In the unprotected area, it contributed about 15.2 percentage of the biomass **(Table** 29).

Table 28: Percentage Contribution of Cressa cretica at Dhordo

Details	**Restoration Site (A)**	**Degraded Site (B)**	***Prosopis* Area (C)**	**Total**
Biomass (kg/ha)	**213.1**	**98.2**	**93.4**	**404.7**
Mean total Biomass (kg/ha)	**2872.5**	**342.1**	**314.9**	**3529.5**
% Contribution of Cressa to the mean total Biomass	**7.4**	**28.7**	**29.7**	**11.5**

Table 29: Percentage Contribution of Cressa cretica at Bhirandiyara

Details	**Unploughed**	**Ploughed**	**Slope Broad**	**Slope Vertical**	**Slope Horizontal**	**Total**	**Outside**
Biomass	**103.1**	**444.1**	**436.7**	**210.0**	**407.6**	**1601.5**	**193.4**
Mean Total Biomass (include C. *haspan)*	***2358.7***	***1677.7***	***1321.4***	***1030.7***	***1175.5***	***7564***	***1274.1***
% of Cressa to Mean Total Biomass	***4.4***	***26.5***	***33.0***	***20.4***	***34.7***	***21.2***	***15.2***

5.8 SALINITY VS GRASS BIOMASS PRODUCTIVITY

Figure 18: *Aeluropes* sp.-Biomas Vs Salinity (Bhirandiyara)

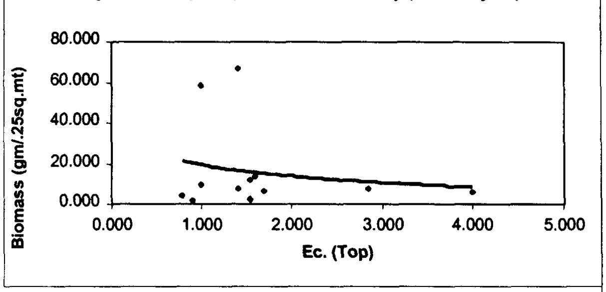


Figure 19: *Cyperus* sp. - Biomass Vs Salinity (Dhordo)

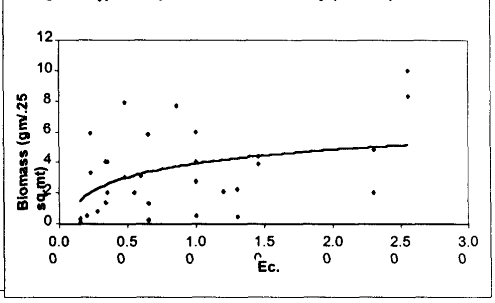


Figure 20: *Sporobolus* sp. - Biomass Vs Salinity (Dhordo)

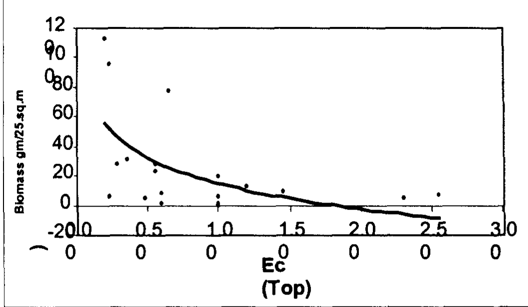


Figure 21: *Scirpus* sp. - Biomass Vs. Salinity (Bhirandiyara).

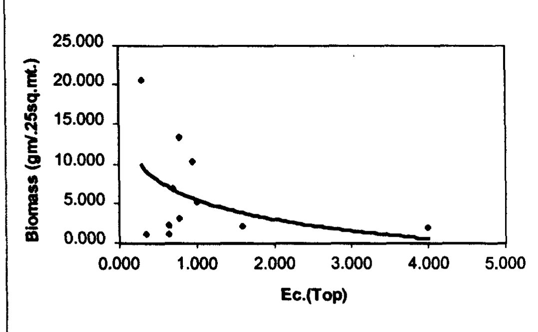


Figure 22: *Cenchrus* sp.- Biomass Vs Salinity (Dhordo).

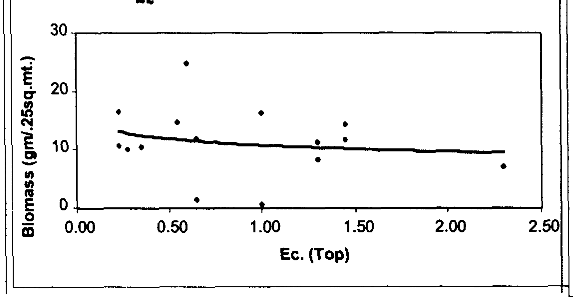


Figure 23: *Dichanthium* sp. – Biomass Vs Salinity (Dhordo).

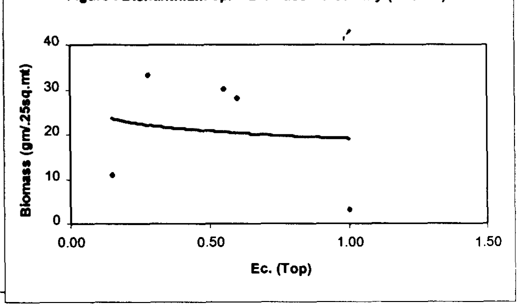
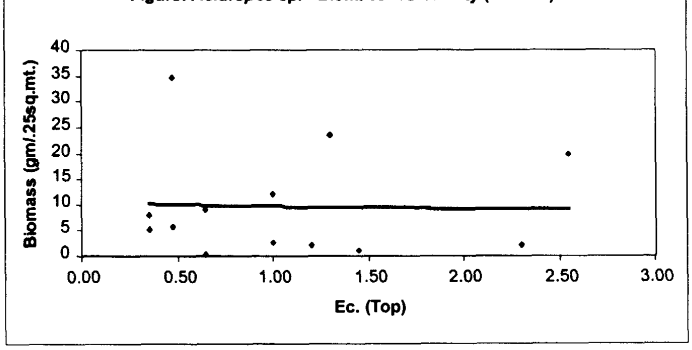


Figure 24: *Aeluropes* sp. - Biomass Vs Salinity (Dhordo).



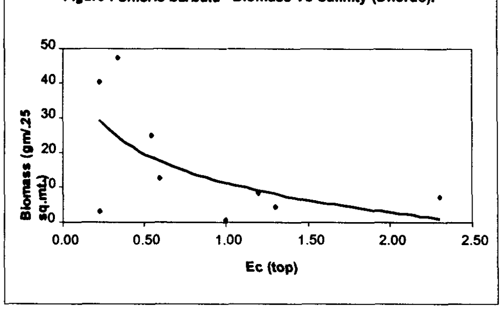


Figure 25: *Chloris barbata* - Biomass Vs Salinity (Dhordo).

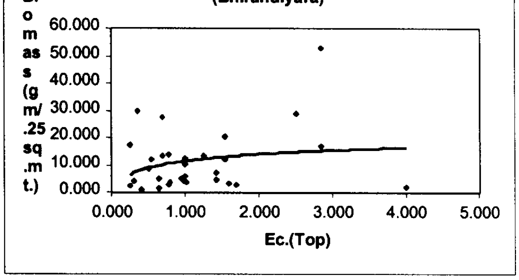


Figure 26: *Cressa cretica*- Biomass Vs Salinity (Bhirandiyara)

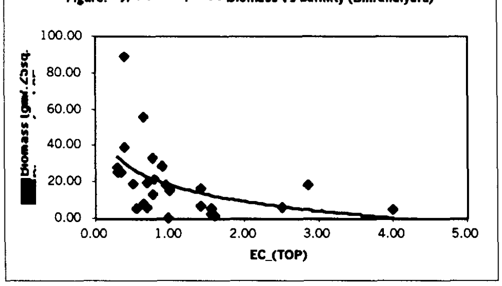


Figure 27: *Cyperus haspans* - Biomass Vs Salinity (Bhirandiyara)

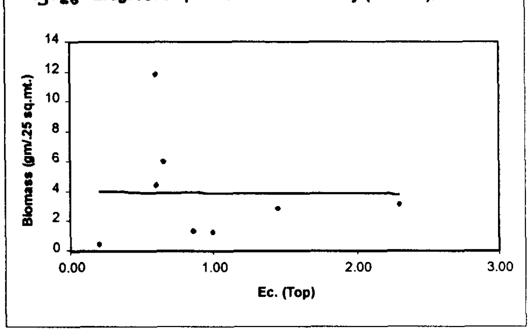


Fig. 28 *Eragrostis* sp.- Biomass Vs Salinity (Dhordo).

The variation in the productivity of different grass species under the same area lead to an assumption that, there were certain soil parameters, which may alter or govern the productivity of the species. Among many soil parameters, soil salinity was considered as a major factor. Many plants fail to grow in high saline areas because, various plant species have different level of salinity tolerance, and this may lead to changes in their productivity. Therefore, an analysis of soil factors with the productivity of different plant species was carried out to understand whether salinity has any effect on the plant production. Figures 18 to 28 clearly show that salinity has positive negative and neutral effects on the productivity of various species.

At Dhordo restoration site, the distribution of all the selected species were restricted with in 2.5 EC level whereas it increased up to 4 EC at Bhirandiyara site. The species such as *Cyperus haspan*, *Cyperus* sp., *Dichanthium annulatum, Cenchrus* sp., *Chloris barbata*, *Sporobolus* sp., and *Scirpus* sp., showed a declining trend with increasing salinity level. Interestingly, the distribution of *Dichanthium annulatum* was restricted within EC level 1.0 while productivity *Sporobolus* sp., reached minimum at EC level 3.0. The productivity of *Aeluropus logopoides* was not affected by salinity up to 2.5 EC **(Figure** 24) above which it showed a sharp decline **(Figure** 18). Cressa *cretica* is the only species, which showed no changes in the biomass productivity up to 4 EC level

6. DISCUSSION

In Banni, animal husbandry plays a vital role in the economy of rural inhabitants and currently, the area supports 26,084 livestock population and provides livelihood to 10,949 human inhabitants of the area. Banni grassland also attracts over 2 lakhs of immigrant livestock (sheep, goat, cattle and buffalo) during normal rainfall years. In addition to these, increase in the spread of *Prosopis juliflora* and saline area during the recent decades further intensified the degradation of grassland resources and thereby affects the life of the local people.

To develop Banni as a self-sustained system, the Gujarat Ecology Commission has implemented restoration efforts in Banni area. Though, there are reports on the failure of artificial restoration of degraded grasslands (Bronner 1990 and Westoby *et al.* 1989), GEC's activities were fairly successful and recovery of the degraded and saline land could be clearly visualized from first year results. This includes higher species diversity, grass cover and biomass in the two restoration sites than the unprotected and *Prosopis juliflora* infested areas. The net above ground production estimated for nine USA grasslands by Sims and Singh (1971) ranged from 107 g/m^2 (1070 kg/ha) (ungrazed short prairie) to 512 g/m^2 (5120 kg/ha) (grazed tall grass prairie). The obtained biomass during the month of November / December in high saline tract of Bhirandiyara was 2 times and Dhordo was about 3 times higher than the minimum biomass recorded by Sims and Singh (1971). Dense growth of grass cover developed in the restoration sites reduced the evaporation rate and thereby the surface soil salinity, which in turn reduced from 13 EC to less than 4 EC in the Bhirandiyara restoration site. This highlights the fact that, the productivity of any degraded and saline lands could be improved through proper management inputs.

Higher availability of species and its biomass in the restoration site than the unprotected and *Prosopis juliflora* infested areas needs an explanation. Taking the protected and unprotected area into consideration, the barbed wire and trench fencing totally prevented livestock grazing in the former whereas grazing was prevalent in the latter. Grazing is complete and or partial removal of living or dead aboveground parts of plants (Hodgson 1979). The general effect of grazing is the reduction of perennial grasses, which are removed during the germination and recruitment stage. Overgrazing causes retrogression, moderate grazing decelerates the rate of succession whereas light grazing and complete protection accelerate the successional process (Penfound 1964).

Apart from the climatic factors, and soil salinity, the grazing pressure would principally govern changes in grassland biomass of an area. Grazing influences competitive patterns, so that either preferentially grazed species lose competitive power to less grazed ones and subsequently decrease (Werger 1977, Walker 1987) or remain dominant in non grazed patches (McNaughton 1979, Stuart-Hill and Tainton 1989). The first change was noticed in the unprotected areas where heavy livestock grazing recorded a noticeable reduction in palatable perennials like *Sporobolus* sp., *Dichanthium annulatum, Chloris barbata* and complete absence of *Cenchrus ciliaris.* The latter was recorded mainly from the restoration sites where the above mentioned grass species recorded significant increase in biomass.

Desert savannas are relatively less interactive as a result of low biomass (Khilmi 1962, Roberts 1987) and their dynamics are mainly event-driven (Westoby 1980). Changes in constraints, particularly rainfall, beyond the influence of the system cause stepwise, unpredictable changes in vegetation. It was believed that, nomadic livestock may have a comparatively little influence on the vegetation composition and production (Ellis and Swift 1988) as most animals migrate in pursuit of water and fodder in dry season (Noy-Meir 1980) a condition common in Banni grassland. Natural events such as temporary droughts may change an area with perennials into one dominated by ephemeral, but grazing prevents renewed change from ephemeral to perennial vegetation when weather conditions change. The conclusion of Ellis and Swift (1988) that noma'dic herds cause no change in the vegetation may be true, their effect is rather to prevent change, locking the vegetation in a phase dominated by ephemeral. However, large continuous areas of such event-driven systems are kept in the same phase for a long time leading to exhaustion of seed sources, forming a further constraint on changes. Thus, herbivores act as a major instrument in modifying the grasslands (Sarmiento 1983, 1992 and Medina 1987). This situation actually occurrs in many parts of Banni, therefore, to enrich the natural seed bank, reseeding was enforced in the restoration sites.

Further, overgrazing not only degrade the land but also forms a major causative factor for the massive expansion of *Prosopis juliflora.* If grasses are destroyed by heavy grazing, more water becomes available for trees and shrubs (Knoop and Walker 1985), leading to changes in the interactive pattern and to an increase in woody vegetation (Stuart Hill and Taintan 1989, Skarpe 1990). This is one of the main causes of widespread invasion of bush into heavily grazed dry rangelands (Walter 1954, Noy-Meir 1982, Archer 1989). Thus, overgrazing in Banni helped *Prosopis juliflora* to expand in most areas. Decrease in herbaceous vegetation following heavy grazing may also lead to physical changes in soil properties, reducing water infiltration and water holding capacity (Ruess 1987). This situation leads to soil degradation in many parts of Banni.

Tropical savannas are commonly defined as strongly seasonal plant communities with a continuous graminoid component and a discontinuous woody component (Walker and Gillisin 1982, Huntly 1982). Trees in semi arid regions are viewed as having the potential to increase forage production, reduce soil erosion, improve soil fertility and reverse Desertification (Nair 1984, Young 1987, Steppler and Nair 1987). However, reports on the effect of trees on savanna grasses and soil are inconsistent. Under some circumstances herbaceous-layer productivity is lower under tree canopies than in nearby open grasslands (Ward and Cleghorn 1964, Grunow *etal.* 1980, Dye and Spear 1982, Walker and Noy-Meir 1982) whereas in other instances, the grassland productivity is higher under tree canopies than in nearby open grasslands (Singh and Lal 1969, Holland 1980, Maranga 1984). Further, it has been reported that, compared to open grassland, tree canopy reduces total solar radiation, air temperature and wind velocity and thereby decreases the potential evapo-transpiration (PET) in the shaded area. Further, soil moisture and fertility was also high in the immediate surroundings of tree canopy. These factors are extremely favourable to the development of herbaceous stratum under the tree canopy. Thus, production would be normally 1.5 to ,'4 times higher in the shade than in open sunlight (Belsky *et al.* 1989, Le Houerou 1993 and Grouzis *et al.* 1995). However, the positive effect of trees on the herbaceous layer production is generally associated with savanna with low tree density (Grouzis *et al.* 1997). Contrary to this, negative impact of trees on the production of herbaceous stratum in certain areas has also been reported (Cesar 1991 and Mordelet and Menaut 1995). Further, increase of soil fertility under canopy is largely due to precipitation (Kellman 1979), redistribution of nutrients from deep to superficial horizons (Bosch and Van Wyk 1970, Chariey and Cowling 1986), nutrient transport through interspecific micorhiza (Grime *et al.* 1987) and excretions of domestic and wild animals (Akpo 1993). Drier and drought conditions limit these process (Hogberg 1986) and thereby the availability of soil nutrients. This may be true in case of dense *Prosopis juliflora* growing under arid condition in the Banni area where severe drought prevails with highly erratic and scanty monsoon. Further, saline soils may adversely affect plant growth and microbial population. However, very little is known concerning the effect of salinity on soil micro-organisms. The nitrifying organisms are considered more sensitive to salts. Saline soils may constitute an unfavourable habitat for the growth and multiplication of rhizobia, which fix the nitrogen in the root nodules of legumes. Due to high density of *Prosopis juliflora* and inherent soil salinity in Dhordo, only aggregation of grass species was seen in suitable areas under tree canopy and this led to very low productivity in the area than that of restoration and unprotected area. This suggest a competitive interactions between trees and herbs as reported earlier in other parts of the world (Ward and Cleghorn 1964, West 1969, Beale 1973, Clary and Jameson 1981, Dye and Spear 1982, Walker *et al* 1986).

Soil moisture is one of a major factor, which governs the germination and growth of grass species. Soil moisture was reported high during the first half of rainy season (June to September) in the open grassland while it was higher during second half (September to October) under tree cover (Bernhard-

Reversat 1982, Joffre 1987 and Grouzis *et al.* 1995). This could be one of the reason for obtaining peak biomass during September and October in the unprotected and restoration site where the tree cover is totally absent while it was in November in the *Prosopis juliflora* infested area where dense canopy of the plant exists. In addition to these, the grass growing inside shrubby dense thorny bushes of *Prosopis juliflora* were inaccessible to the livestock and this would enable a minimum change in the biomass between different months and also produce higher biomass than the unprotected area during the end of the study period.

At Dhordo restoration site, with the complete absence of grazing pressure, there was fluctuation of biomass productivity during different months. The decrease was due to death and shattering of annual plants and tillers of perennial grasses following maturity. The bulk of live vegetation is thus transferred to standing dead and litters compartments during the late post monsoon. The same was also reported by Heady (1960) and Rattiff and Heady (1962), and they attributed the decline in the total dry weight of the herbage to approaching dry season, normal decline following maturity, seed and leaf shattering, insect and rodent consumption. The variation in biomass obtained in Dhordo is mainly due to natural process of drying / dying and or germination of different grass species due to an unusual heavy rainfall, received during the month of September at Dhordo. This created waterlogging in many areas of restoration and surrounding sites. As a result, the newly germinated grass plants, which got submerged under water, died. However, thereafter, the high moisture availability helped the viable seeds to germinate and survived or established grass plant to grow vigorously. This helped in increasing the biomass during the end of November. This situation also prevailed in the unprotected area of Dhordo. As a result, the availability of grass cover in many parts of Banni distributed the grazing pressure, and thereby the productivity showed a slight upward trend in November in the unprotected area. Though, the recorded biomass was comparatively less (September and November) in the *Prosopis juliffora* area, minimum grazing access due to the dense coppicing thorny branches facilitate an overall increase of 17.9 per cent biomass between September and November.

In the restoration sites, the productivity was found higher in the unploughed area than that of ploughed area. In the ploughed area the natural seed bank as well as tillers and rhizome of grass plant were disturbed due to ploughing activities while in the unploughed area these were left undamaged. Therefore, in the unploughed area, few showers activated the vegetative growth of grass plant from the tillers or rhizome. In the ploughed area, grass has to develop from the germination of seeds of different species sown in that area. The grass seeds have certain adaptations to survive in the harsh conditions. All the seeds of a grass plant will not grow after a single shower. In a single grass plant, seeds produced in the same spike have different levels of dormancy (an adaptive mechanism), which might germinate after it receives a single or multiple showers. For example, seeds of grass species such as *Cenchrus* sp. require certain amount of moisture to wash the inhibitors present in its seed coat before germination. This could be the possible reason for the late recruitment / germination of certain grass species like *Cenchrus* sp. in the ploughed area. Further, after the germination, the plant would take at least one full season to establish and this may be an important reason for obtaining more biomass from unploughed areas than the ploughed areas at both the restoration sites. However, the fast recovery due to soil working was evident through the increased productivity in the ploughed area of Dhordo and different slopes of Bhirandiyara restoration sites.

Except *Cyperus rotundas* and *Cressa erotica*, which showed a uniform distribution, other grass species exercised either random or aggregation. Plant community is the composition of spatially and temporally integrated species that retain their individuality in an area (Mishra, 1968; Mueller-Dombois and Ellenburg, 1974). Plant communities and associations characterise the “habitats” in which transformations, accumulations and flow of energy are involved. The variation in distribution of different grass species was caused by several factors like soil conditions, vegetative propagation, quantity and dispersal of seeds, grazing, predation by insects, biotic activities and diseases. In a uniform vegetation class E is always larger than class D. However, the situation where E is smaller than class D denotes eariy stages of succession or severe biotic influences on the community. Latter process was recorded on narrow vertical and horizontal slopes of Bhirandiyara restoration site, which indicates the successional process in that area.

At Bhirandiyara site, waterlogging is a common feature during heavy rainfall years. This creates a favorable environment for the growth of *Cyperus haspan* and *Cyperus rotundus.* Such a favourable situation prevailed during September 1997. Within 36 hours, the area received about 458 mm rainfall, which resulted in waterlogging for more than a fortnight. This enabled the rhizome of C. *haspan* to grow enormously and vigorously in and outside the restoration site, which is less palatable due to its high fibrous nature. Further, the implementation of soil amendments carried out about 75 per cent of the restoration site disturbed the rhizome of C. *haspan*. These brought out higher cover and biomass availability during the initial period in the unprotected area, which was slightly higher than the restoration site of Bhirandiyara as well as unprotected and *Prosopis juliflora* area of Dhordo site.

As reported by Christina (1992), the establishment of quality perennials gradually eliminates the unwanted annuals like *Cyperus haspan.* Therefore, it is likely that the seeds of *Sporobolus sp., Cenchrus* sp., *Dichanthium annulatum* etc., sown in these areas would gradually replace or eliminate the *Cyperus haspan* after its establishment due to competition. Further, drier condition generally affects the survival of *Cyperus haspan* whereas the perennial species sown in this area are capable of surviving even under less or minimum moisture availability. This was found true on the narrow slopes and parts of other sub-compartments of the Bhirandiyara restoration site. Though the land condition existed under similar state, protection and reseeding alone made it possible to replace domination of *Cyperus haspan* by productive perennials in the restoration site.

In the unprotected area, the species like *Aeluropus logopoides* dominates during the latter part of monsoon. As per locals, the cattle preference for the *Aeluropus logopoides* and *Eragrostis sp.* is less. Livestock exhibit preferences not only for certain plant species, but for the same species under different stages of growth and even for the various parts of an individual plant (Hafex *etal.* 1969 and Arnold *etal.* 1966).

The species like *Cyperus rotundus, Cyperus haspan* and *Scirpus* sp. are the only species, which showed a tremendous decrease during the course of the post monsoon in the restoration site. These three species require high moisture, therefore, lack of moisture during November in open grassland leads to shrinkage and death.

Salinity remains one of the world's oldest and most serious problems for plant production. The adverse effect of salt stress on growth and dry matter production have been extensively studied (Meiri and Poljakoff-Mayber 1969, Tal 1971, Greenway *et al.* 1983, Eumawat e/ *al.* 1991, Khan *et al* 1992, Smith *et al.* 1992, Rogers and West 1993 and Staley *et al.* 1993). None of the plants are virtually salt tolerant to any high degree. (Gour and Kumar, 1993). It was reported that, salt tolerance increases with growth of the plant (Gill 1985, 1987 and 1988). Contrary to this, it was observed from the present study that, even saline tolerant species like *Aeluropus logopoides* and *Sporobolus* sp., showed decreasing productivity with the increasing salinity.

7. CONSTRAINTS

A study Committee of the National Academy of Science, U.S.A (1974) defined restoration as the replication of site conditions prior to disturbance. Jordan *et al.* (1988) cited that, restoration is the re-creation of entire communities of organisms, closely modelled on those occurring naturally. Currently only a limited theoretical foundation can be applied in site restoration, and there are very few cases in which the theories have actually been tested (Janzen 1988, Uhl 1988, Uhl *et al.* 1990 and Nepstad *et al.* 1991). As knowledge builds up with experience, it will be possible to derive generalized principals of restoration ecology and management. The above view clearly highlights that restoration is highly challenging task and it takes a considerable time-scale than the normal political and national plan cycle (Singh and Jha 1992). For example, the natural recovery of total soil nitrogen in a 20 year age mine spoil would take a period of 200 years (Srivastava *et al.* 1989). The successful restoration of degraded lands will depend on the continued effectiveness of motivation, publicity amongst people and organization of societal infrastructure, in which Governmental and Non Governmental agencies may play a vital role.

This has been accomplished by the GEC through GUIDE and VRTI. The natural recovery in the restoration sites are promoted by the activities currently being employed by GUIDE and VRTI at two sites of Banni, namely Bhirandiyara and Dhordb. Since successional process would take considerable time, the current situation made it possible to obtain only moderate restoration that too after the 1997 monsoon. Under these circumstances, it would take at least two more years to bring out the management guidelines for this area. This technical report, however, highlights one-year (1997) recovery of the restoration sites in relation to grazed / degraded and *Prosopis* infested areas. Further, the production and dispersal of large quantities of seeds produced by the established grass plants and their tillers would certainly increase the richness of species and change the trend in the successive years.

8. MAJOR ACHIEVEMENTS

At Dhordo the biomass production estimated in September 1997 and November 1997 was 3 to 7.8 times higher than the unprotected and 5.5 to 8 times higher than *Prosopis juliflora* infested areas.

Over 1,75000 kg grass was harvested from this site during December 1997. As per local villagers, this fodder is sufficient to meet their livestock needs of 6 villages located around Dhordo for more than a year.

At Bhirandiyara restoration site the biomass gradually increased from 1115.9 kg/ha in October to 2228.7 kg/ha in December and thus, showed an increase of 99.7 per cent whereas it decreased to 31.5 per cent in the unprotected area located adjacent to the site.

To reduce the salinity of the Bhirandiyara restoration site, several soil amendments were carried out. In which, narrow slopes of 0.5m height x 3m wide were found more promising in the productivity of palatable grass species. The dense growth of grass species in various amendment areas also helped in reducing the soil water evaporation and thereby decreased the surface soil salinity to a great extant (EC 1-4.5) inside the restoration site. Thus the restoration site is experiencing low salinity when compared to outside area where the land is exposed to high evaporation under the absence (due to excessive grazing) of grass cover.

Highly palatable species like *Sporobolus, Cenchrus, Chloris* and *Dichanthium are* growing luxuriantly inside both the restoration sites. The results obtained during the first year (September 1997 to December 1997) clearly enhances the scope that, eradication of *Prosopis juliflora,* protection from grazing and soil management along with reseeding could improve the productivity of any degraded grassland.

9. REFERENCES

Acker, S. A, 1990. Vegetation as a component of a non-nested hierarchy: a conceptual model. J. Veg.Sci. 1:683-690.

Akpo, L. E. 1993. Influence du couvert ligneux sur la structure et le fonctionnement de la strate herbacee en milieu sahelian. Les determinants ecologiques. Paris: TDM, ORSTOM. Pp 174.

Arnold, G. W., J. Ball, W. R. McManus and I. G. Burn. 1966.Studies on the diet of grazing animal. 1. Seasonal changes on the diet of sheep grazing on pastures of different availability and composition. Australian Journal of Agriculture Research. 17: 543-556.

Bawa, R. 1995. Biomass dynamics of Himalayan grassland. Int. J. of Ecology and Environmental Sciences.21: 25-36.

Beale, I. F. 1973-Tree density effects on yields of herbage and tree components in southwest Queensland mulga *(Acacia aneura}* scrub. Tropical grassland. 7. Pp 135-142. Belsky, A. J., R. G. Amundson, J.M. Duxbury, S. J. Riha, A. R. Ali and S. M. Mwonga. 1989.

The effects of trees on their physical, chemical and biological environments in a semi-arid savanna in Kenya. J. Appl. Ecol. 26:1005-1024.

Bemhard-Reversat, F. 1982. Biogeochemical cycle of nitrogen in a semi-arid savanna. Oikos,38: 312-332.

Bhimaya, C. P. and L. D. Ahuja. 1969. Criteria for determining condition class of rangelands in western Rajasthan. Ann. Arid Zone. 8: 73-79.

Bhimaya, C. P, R.N. Kaul and L.D. Ahuja. 1967. Forage production and utilization in arid-and semi arid rangelands of Rajasthan. Proc. Symp. Nat. Inst. Sci. India. Pp 215-223.

Bosch, 0. J. and J. P. Van Wyk. 1970. The influence of bushweld trees on the productivity of *Panicum maximum: a* preliminary report. Hand Weidingsveren, South Africa, 5: 69-70.

Bradshaw, A. D. 1987. The reclamation of derelict land and the ecology of ecosystems. In: W.R. Jordanian, M.E. Gilpin and J.D. Aber (Eds.), Restoration Ecology. Campridge University press, Campridge, England. Pp 53-74.

Cesar, J. 1991. Les facteurs de production herbacee des savanes humides d'afrique tropicale. IV Congres International des Terres de Parcours, Montpellier, France. Pp 4.

Champion, H. G. and S. K. Seth. 1968. Forests types of India. Manager of Publications.New Delhi. Pp 404.

Charley, J. L. and S. W. Cowling. 1986. Changes in soil nutrient status resulting from overgrazing and their consequences in plant communities of semi-arid areas. Procedings of the Ecological Society of Australia. 3: 28-38.

Clary, W. P. and D. A. Jameson. 1981. Herbage production following tree and shrub removal in the ponyonjuniper type of Arizona. J. of Range Management. 34. Pp 109-112.

Coupland, R. T. 1978. Grassland ecosystem of the world. (Eds.). Cambridge University Press, London. Pp401.

Christina, S. 1992. Dynamics of savanna ecosystems. J. Vegetation Science. 3. Pp 293-300. Dabadghao and Shankamarayanan. 1973. The grass cover of India. ICAR New Delhi. Pp.713.

Dye, P. J. and P.T. Spear. 1982. The effects of bush clearing and rainfall variability on grass yield and composition in southwest Zimbabwae. Zimbabwae Journal of Agricultural Research. 20. Pp 103-118.

Frost, P., E. Medina, J. C. Menaut, 0. Solbrig, 0. Swift and B. Walker. 1986. Responses of savannas to stress and distrubance. Biol. Int. 10:1-82.

Gadgil, M and V. M. Meher-Homji. 1985. Landuse and productive potential of Indian savannas. In: J. C. Tothil and J. J. Mott (Eds.) Ecology and Management of the world's savannas. The Australian Academy of Sciences, Canberra. Pp. 107-113.

Ganguli, B. N., R. N. Kaul and K. T. N. Nambiar. 1964. Preliminary studies on desert top feed species. Ann. Arid zone, 3: 33-37.

GAU, 1989. Status report, Vol. 1. National Agriculture Research Project, North west agroclimatic zone, Gujarat agricultural University, Sardar Krushinagar.

Gour, H.N. and A. Kumar, 1993. Soil salinity, plant growth and microbes. In: Management of salt affected soils and waters. (Eds. L.L. Somani and K.L. Totawat). Agrotech Pupl. Udaipur.

Goodall, D.W. 1963. The continuum and the individualistic association. Vegetatio. 11. Pp 297-316.

Grime, J. P., J. M. Mackey, S. H. Hillier and D. J. Read. 1987. Floristic diversity in a model system using experimental microcosms. Nature, 328: 420-422.

Groombridge, B. 1992. 1994 IUCN Red list of Threatened Mammals. IUCN Gland, Switzerland and Cambridge, UK. Pp 39.

Grunow, J.O., H. T. Groeneveld and S.H.C. Du Toil 1980. Biomass cycles, accumulation rates and nutritional proceedings of the grassland society of South Africa. 15. Pp 157-161.

GUIDE, 1998. Status of Banni grassland and exigency of restoration efforts. Gujarat Institute of Desert Ecology, Bhuj.

Hafex, E. S. E., M. W. Schein and R. Ewbank. 1969. The behaviour of cattle. Pp 225-295. In: E. S. E. Hafez (eds). The behaviour of domestic animals. Bailliere. Tindall and Cassell ltd, London.

Hodgson, J. 1979.Nomenclature and definition in grazing studies. Grass and forage science. 34: 11-18.

Holland, V.L. 1980. Effect of blue oak on rangeland forage production in central California. Ecology, Management and Utilisation of California Oaks. (Ed by T.R. Plumb). Pacific southwest forest range experiment station, Berkeley. Pp 314-318.

Huntly, B.J. 1982. Sauthem Affrican savannas. Ecology of tropical savannas (Ed by B.J. Huntley and B.H. Walker), Springer-Verlag, NewYark. Pp 101-119.

Jadhav.R. N., M. M. Kimoti and A. K. Kandhya. 1992. Grassland mapping / monitoring of Banni, Kachchh (Gujarat) using remotely sensed data. Land Resources Division, Remote Sensing Application Group, Space Application Centre, Ahmedabad.

Janzen, D.H. 1988. Tropical dry forests: The most endangered major tropical ecosystem. In Biodiversity (Eds. E.O. Wilson and F.M. Peter). Washington D.C. National Academy Press. Pp 130-177.

Jordan, W.R., M.E. Gilpin and J.D. Aber. 1987. Restoration Ecology. A synthetic approach to ecological research. New York. Cambridge University Press.

Joffre, R. 1987. Contraintes du milieu et reponses de la vegetation herbacee dans les dehesas de la Sierra Norte (Andalousie, Espagne). Thesis USTL, Montpellier. Pp 201.

Kadikar, P. 1994. Status of Banni (Kachchh, Gujarat) grassland by 2000 AD using multiple remote sensing satellite data. Dissertation. Gujarat University, Ahmedabad.

Kanodia, K. C. and B. D. Patil. 1983. Pasture development. In: Desert resources and technology. Vol. I (Eds. A. Singh), Jodhpur.

Kanodia, K.C., K.C. Velayudhan and P. Rai. 1978. Approaches and systems in augmentation of grasslands in semi arid zone with special reference to Bundelkhand tract. Intern. Symp. Arid Zone. Research and Development, CAZRI, Jodhpur, 6-8^ Feb. abstract. Pp 111.

Kelman, M. 1979. Soil enrichment by neo-tropical savanna trees. Journal of ecology. 67: 565-577.

Kent, M. and P. Coker. 1992. Vegetation description and analysis. A pratical approach. CRC and Belhaven press. Pp. 363.

Le Houerou, H. N. 1993.Environmental aspects of fodder trees and shrubs plantation in the Mediterranean basin. In : Papanastasis, V. (Ed.), Fodder trees and shrubs in the Mediterranean Production systems: Objectives and expected results of the EC research contact. Pp11-34. Brussels: Commission of the European Communities, EUR 1445, v-205.

Leafe, E. L. 1988. The history of improved grasslands. In: The grass crops. (Eds.) M. B. Jones and A. Lazenby. Chapmann and Hall. Pp. 1-20.

Maranga, F. K. 1984. Influence *of Acacia tortilis* trees on the distribution of *Panicum maximum* and *Digitaria macroblephara* in south central Kenya. MS Thesis. Texas A and M University. McNaughton, S. J. 1967. Relationship among functional properties of Califomian grasslands. Nature.

216: 168-169.

McNaughton, S. J. 1979. Grazing as an optimisation process, grass-ungulate relationships in the Serangetti. Am. Nat. 113: 691-703.

Medina, E. 1987. Requirements, conservation and cycle of nutrients in the herbaceous layer. In:

Walker, B.H. (Eds) Determinants of tropical savannas. Pp.39-66. ICSU press, Miami.

Mishra, R. 1968. Ecology work book. Oxford and IBH publishing co. New Delhi. Pp 244.

Mordelet, P. and J. C. Menaut. 1995. Influence of trees on above ground production

dynamics of grasses in a humid savanna. Journal of vegetation science. 6: 223-228.

Muller-Dombois and H. Ellensberg. 1974. The aims and methods of vegetation ecology. John Wiley and sons. New York. Pp. 547.

National Research Council (NRC), 1983. Environmental change in the west African Sahel. Washington D.C. National Academy Press.

National Research Council (NRC), 1989. Science and Technology Information Services and Systems in Africa. Washington D.C. National Academy Press.

Nepstad, D.C., C. Uhl, A.S. Serrao. 1991. Recuperation of a degraded Amazonian land scape: Forest Management and Agricultural Restoration. Ambio. 20 (6): 248-255.

Noy-Meir, I. 1975. Stability of grazing systems: An application of predator prey graphs. J. Ecol. 63:

459-481.

Odum, E. P. 1960. Organic production and turnover in old-field succession. Ecology. 41: 34-49.

Paliwal, K.V. 1977. Nutrient requirement of salt-affected soils. Proc. Indo-Hungarian Sem. Management of Salt Affected Soils, Kamal, Pp 202-218.

Pandeya, S. C. 1974. Ecology of grassland of Sagar, M.P. IIA. Composition of the fenced grassland association. J. Indian Bot. Soc. 43: 577-605.

Pandya, S. M. and V. K. Siddha. 1982. Ecological studies of arid regions of Kutch (Gujarat state). Final progress report, Dept. of Biosciences, Saurashtra University, Rajkot.

Parikh, J. and S. Reddy. 1997. Sustainable regeneration of degraded lands. Tata McGraw -Hill Publ., New Delhi.

Penfuund, W. T. 1964. The relation of grazing to plant succession in the tall grass praire. Journal of Range Management. 17: 256-260.

Peters, R. L. 1985. Global climate change: A challenge for restoration ecology. In: Restoration and management notes. 3: 62-67.

Premadasa, M. A. 1990. Tropical grasslands of Sri Lanka and India. J. Biogeography. 17: 395-400.

Peters, R.L. and J.D.S. Darling. 1985. The green house effect and nature reserves. Bioscience, 35:

Pp. 707-717.

Quadar A. 1994. Physiology of salt tolerance. In Salinity Management for Sustainable Agriculture (Eds. D.L.N. Rao et al.), Central Soil Salinity Research Institute, Karnal, India.

Rahmani, A. R. 1989. Grassland birds of the Indian subcontinent: A review. ICBP Technical Publication No. 7:187-204.

Rahmani, A. R. 1997. A study on the ecology of grassland of Indian plains with particular referance to their endangered fauna. Bombay. Nat. Hist. Soc., Bombay.

Ram, J., J. S. Singh and S. P. Singh. 1989. Plant biomass, species diversity and net primary production in a central Himalayan high altitude grassland. J. of Ecology. 77:456-468.

Raheja, P.C. 1966. Rajastan desert can bloom with forage. Indian Farming. 15. Pp 47. Raunkiaer, C. 1934. The life forms of plants and statistical plant geography. Oxford University Press, Oxford. Redmann, R. E. 1992. Primary productivity. In: R.T. Coupland (Eds.)Ecosystem of the world. Elsevier. Netherlands.

Roberts, D. W. 1987. A dynamical systems perspective on vegetation theory. Vegetation. 69: 27-33.

Rodgers, W. A. 1986. The role of fire in the management of wildlife habitats - A review. Indian Forester. 112 (10) 845-857.

Ruess, R. W. and S. J. McNaughton. 1987. Grazing and the dynamics of nutrient and energy regulated microbial process of Serengeti grasslands. Oikos. 49:101-110.

Ruess, R. W. 1987. The role of large herbivores in nutrient cycling of tropical savannas. In: Walkar, B. H. (Eds.) Determinants of tropical savannas, pp 67-91. ICSU press, Miami. Sampson, A. W. 1952. Range management. New York, Wiley. Sankar, V. and K. C. Velayudan. 1979. Primary productivity, compartment transfer and system transfer functions in Iselima Laxum grassland. Annals of Arid zone. 18 (3): 143-152. Sarmieento, G. 1983. The savannas of tropical America. In: Bouriiere, F. (Eds). Ecosystems of the world 13. Tropical savannas. Pp 245-288. Elseveier. Amsterdam.

Sarmieento, G. 1992. Adaptive strategies of perennial grasses in south American savannas. J. Veg. Sci. 3: 325-336.

Saxena, S. K. 1992-Banni grasslands and halophytes. In: A dossier on Kachchh, Gujarat Ecology Commission, Vadodara.

Sankamarayan, K. A.1977. Impact of over grazing on the grasslands. Ann. Arid Zone. 16: 349-359.

Sale, J.P. 1981. The importance and values of wild plants and animals in Africa. Gland, Switzerland.IUCN.

Sims, P. L and J. S. Singh. 1971. Herbage dynamics and net primary production in certain ungrazed and grazed grassland in north America. Pp 59-124. In: N. R. French (Eds). Preliminary analysis of structure and function in grasslands. Range Sci. Dep. Sci. Ser. No 10., Colorado State Univ., Fort Collins. Singh, J.S. 1988. The environmental problems: Issues and challenges. In: K.S. Valdiya (Eds.), Kumaun: Land and People. Gyanodaya Prakashan, Naini Tal. Pp 347-351. Singh, K.S and P. Lal. 1969. Effects of Kijari *(Prosopis spicigera)* and Babool *(Acacia arabica)* trees on the soil fertility and profile characteristics. Annals of Arid Zones. 8. Pp 33-36. Singh, U. N. and R. S. Ampasht. 1975. Biotic stress and variability in structure and organic (net primary) production of grassland communities atVaranasi, India. Trop. Ecol. 16: 86-95.

Singh, J. S. and P. S. Yadava. 1974. Seasonal variation in composition, plant biomass and net primary productivity of a tropical grassland at Kurukshetra, India. Ecol. Monograph. 44: 351-376.

Singh, J. S. and M. C. Joshi. 1979. Primary production. In: Coupland. R. T. (Eds.) Grassland ecosystems of the world. Analysis of grasslands and their uses. Pp 197-218. Cambridge University press, Cambridge.

Singh, K.N and B. Mohan kumar, 1985. Interactive effects of soil moisture, fertilizers and salinity in crop production. Agric. Rev. 6:8-22.

Singh, J. S. and A. K. Jha. 1992. Restoration of degraded land: An over view. Pp. 1-9. In: J. S. singh (Eds.). Restoration of degraded land: concepts and Stratigies. Rastogi publications, Meerut.

Singh, J.S., Y. Hanxi and P.E. Saise. 1985. Structural and functional aspects of Indian and South East Asian savanna ecosystems. In: J.J. Thothil and J.J. Mott (Eds.). Ecology and Management of Worlds Savannas. The Australian Acad. Sci. Canbera. Pp 34-51.

Srivastava, S.C.,A.K. Jha and J.S. Singh. 1989. Changes with time in soil biomass C,N and P of mine spiols in a dry tropical environment. Canadian J. of Soil Science. 69:Pp 849-855.

Skarpe, C. 1991. Impact of grazing in savanna ecosystems. Ambio. 20: 351-356.

Stuart-Hill, G. C. and N. M. Tainton. 1989. The competitive interaction between *Acasia karrow* and the herbaceous layer and how this is influenced by defoliation. J. Appl. Ecol. 26: 285-298.

Stuart-Hill, G. C. and N. M. Tainton. 1989. The competitive interaction between *Acasia karroo* and the herbaceous layer and how this is influenced by defoliation. J. Appl. Ecol. 26: 285-298.

Uhl, C. 1988. Restoration of degraded land in the Amazon basin. In Biodiversity (Eds. E.O. Wilson and F.M. Peter). Washington D.C. National Academy Press. Pp 326-332.

Uhl, C., D. Nepstad, R. Buschbach, K. dark, B. Kauffman and S. Subler. 1990. Studies of ecosystem response to natural and anthropogenic distrubances provide guidelines for desinging sustainable land-use systems in Amazonia. In: Alternative to deforestation. Steps towards sustainable use of the Amazon rain forest (Eds. A.B. Anderson). Pp 24-42.

Walker, b. H. 1987. A general model of savanna structure and function. In: Walker, B.H. (Eds). Determinants of tropical savannas. Pp 1-12. ICSU Press, Miami. Walker, B. H. and I. Noy-Meir. 1982. Aspects of the stability and resiliance of savanna ecosystem. Ecology of tropical savannas (Ed by B.J. Huntley and B.H. Walker), Springer-Veriag, New Yark. Pp 556-990.

Walker, J. and A. N. Gillison. 1982. Australian savannas. Ecology of tropical avannas (Eds. By B.J. Huntley and B.H. Walker). Springer-Veriag, New Yark. Pp 524.

Ward, H. K. and W. B. Cteghom. 1964. The effects of ring-barking trees in B West 1969

Ward, H.K. and W.B. Cleghom. 1964-The effects of ring-barking trees in rachystegia woodland on the yield of veld grass. Rhodhosean Agricultural journal. 61. Pp 98-107.

Werger, M. J. A. 1977. Environmental destruction in southern Africa: the role of overgrazing and trampling. In: Miyawaki, A. and R. Tuxen (Eds). Vegetation science and environmental protection. Pp 301-305, Maruzen, Tokyo. Yadav, M.S. 1991. Potential grasses for arid zone. In: Dry land Resources and Technology - 6. (Eds. A. Singh and L.L. Somani). Pp 115-119. Yadava, P. S. and J. S. Singh. 1986. Progress in ecology. Vol. 2. In: Grassland vegetation. Todays and Tommorrow's Printers and Publishers. New Delhi. Pp 132.