MAPPING A DRY SHRUB FOREST FOR BIODIVERSITY CONSERVATION PLANNING

(A case study in the Salt range of Pakistan, using remote sensing and GIS tools)

By

GHAYYAS AHMAD

February, 2001

MSc Thesis
Forestry for Sustainable Development

FOREST SCIENCE DIVISION

INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES (ITC)
ENSCHEDE, THE NETHERLANDS

MAPPING A DRY SHRUB FOREST FOR BIODIVERSITY CONSERVATION PLANNING

(A case study in the Salt range of Pakistan, using remote sensing and GIS tools)

By

GHAYYAS AHMAD

February, 2001

Thesis submitted to the International Institute for Aerospace Survey and Earth Sciences in partial fulfilment of the requirements for the degree of Master of Science in Forestry for Sustainable Development

Degree Assessment Board

Prof. Dr. Ir. A. de Gier
Chairman and Head of Forest Science Division (First Supervisor)

Prof. Dr. Ir. F. Mohren
(External Examiner)

Dr. Iris van Duren
(Co-Supervisor)

Dr. Y.A. Hussin
(MSc Students Advisor)

Forest Science Division
INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES (ITC)
ENSCHEDE, THE NETHERLANDS

Disclaimer

ABSTRACT

The Salt Range area in Pakistan is a local biodiversity hotspot. Shrub forests of the area are faced with an increasing problem of forest fragmentation and degradation, which is eroding the original biodiversity. The main objective of this study was to identify priority remnant forest patches for biodiversity conservation planning. Extensive use was made of remote sensing and GIS techniques to achieve the objective. Forest vegetation was selected as a subset of total biodiversity.

Gap analysis and rapid biodiversity appraisal methods were mainly employed in this study. Major forest mosaics of the area were identified from satellite image and then visited on the ground to collect locational, environmental, biological and disturbance data. Line transect sampling design was used in field data collection. Image classification was performed using the Supervised and Knowledge-based classification methods. The degree of forest fragmentation was analysed by deriving some fragmentation statistics. Patch size of the remaining semi-natural forests was selected as the most important criterion for the identification of priority areas. However, patch shape and its location with respect to disturbance gradients was also taken into consideration.

Results indicate that there is a difference in the forest vegetation characteristics of the eastern and the western parts of the Salt range. Remaining semi-natural forests are located mainly within government controlled forestlands, which are also relatively less fragmented as compared to private forests. As expected, semi-natural forests are less disturbed than degraded forests but climax plant species occur in both. The process of forest fragmentation is strongly linked to the existence of roads in the area.

NDVI is a good indicator of forest vegetation of the area. However, regarding the drier western forests, remote-sensing data gives less accurate results. Gap analysis reveals considerable gaps in biodiversity conservation. Most of the identified priority forest patches are excluded from the highest levels of protection.

A total of 17 priority forest fragments for biodiversity conservation have been identified which could form the core areas in any proposed reserve design. Remote sensing and GIS are powerful and useful tools for biodiversity assessment, mapping and conservation planning at the ecosystem or landscape scale.

ACKNOWLEDGEMENTS

I wish to thank the people and the Government of the Netherlands for the award of a fellowship and Raja M. Ashfaque (DG, Pakistan Forest Institute) for nominating me to pursue this course.

I am very grateful to my first supervisor Professor Dr. Ir. A. de Gier for guidance, valuable suggestions and critical comments and for making me aware of the purpose, structure and logic of research. Thanks are due to Dr. Iris van Duren, co-supervisor, who gave some very useful suggestions and new ideas during the course of this work. She was always available for counselling. Dr. G.B. Ingram deserves my thanks for teaching me the interesting subject of biodiversity conservation because of which I decided to select a related research topic. He also supervised the fieldwork in a methodical way. Thanks are also due to the following staff of Forest Science division. To Dr. Y.A. Hussin, for his help in remote sensing issues and in taking keen interest in monitoring the progress of this work, and to Ir. Edwin Keizer for his kind help in fragmentation analysis.

I extend my sincere gratitudes to my colleagues in Pakistan Forest Institute, Dr. Mirza Hakim Khan, Raja M. Zareef, Mian M. Shafiq, Yusuf Khan, Miskeen Ali, and Shah Hussain, for their help in this research and in data collection. Their cooperation contributed greatly in the successful completion of this work.

WWF-Pakistan provided me with the satellite imagery of the study area. For this, I am very grateful to Ali Hasan Habib (DG, WWF-Pakistan). Ms. Mehjabeen Abidi (coordinater GEF, Punjab), took keen interest in this work and helped me by giving some useful information. I also thank the staff of WWF-Pakistan especially Salman Ashraf, Amir, Yasir, and Haris for providing me most of the required data. The cooperation extended by the officials of the local forest and wildlife department, especially Ahmad Hussain is greatly appreciated. I take this opportunity to also thank Mubashar for his hospitality during my visit to Lahore and for taking pains to collect some data for me.

Help, cooperation and friendship of all of my forestry classmates especially Tauheed and all other Pakistani students at ITC is greatly appreciated. And my thanks to Lilliana Caballero who provided me with patch analyst software. In the end, I feel very indebted to my beloved wife Erum, old parents, and relatives who had to endure my absence from home for a long time. Their prayers, support and love are a precious asset.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Research background

Tropical dry forests are a largely neglected resource all over the world. It is one of the most poorly protected forest categories in the world with only 5% area under protection (WCMC, 1996) cited by Kapos and Iremonger (1998). In the global classification of forests given by Borota (1991), shrub forests of Pakistan are placed under the tropical and sub-tropical dry forest category. From an economic point of view, dry forests are not considered 'valuable' as timber is not the major product (Borota, 1991). However, these forests serve the local communities by meeting their needs for fuelwood, fodder and a range of subsistence products besides performing other functions such as the protection of watersheds, providing opportunities for ecotourism and habitats for wildlife. The conservation of natural or semi-natural dry forests is a dire need of the hour in order to preserve original biodiversity and to regulate its use by local communities for meeting their subsistence needs.

The conservation of biodiversity has become a major concern with the international community ever since the Convention on Biological Diversity (CBD) was drafted in Rio in 1992. Forests and woodlands cover nearly 40 percent of the earth's land surface, and they are the most biologically diverse ecosystems in most parts of the world (WRI, IUCN and UNEP, 1992). Forests are arguably the single most important banks of global biodiversity (Kapos and Iremonger, 1998). Forest fragmentation may negatively influence the forest's original biodiversity at the levels of genes, species, and communities leading ultimately to the loss of biodiversity (Zuidema, Sayer and Dijkman, 1996). Natural or semi-natural old forests are important for preserving the original biodiversity, as they provide a habitat for certain specialised forest-related species (Parviainen and Päivinen, 1998). Ancient forest species are considered important in terms of nature conservation because they combine both qualitative (forest quality) and quantitative (diversity) conservation criteria (Peterken 1996). Natural forests are also important as a setting for outdoor recreation and tourism. The only means to preserve the floral and faunal species typical to such forests is by establishing a representative network of conservation areas including cores, buffers and corridors. Conservation of biodiversity requires management of entire landscapes, not just protection of individual reserves (Noss, 1990). Core areas managed for the protection of biodiversity could form the backbone for any regional land conservation system surrounded by buffer zones where compatible human uses could be allowed.

Pakistan is a forest poor country with only 4% of its area under good forest cover with a high annual loss rate of 0.4% (WCMC 1992; WRI 1992). Over the last few decades, the government has taken several steps to address the growing problems of deforestation, land degradation and habitat loss. A national conservation strategy was prepared in 1992. There are 189 protected areas in the country (IUCN, 1990) including 10 National Parks, 82 Wildlife sanctuaries, and 83 Game reserves, as well as 14 unclassified reserves (private, proposed, or recommended). The total protected area is 7 238 584 hectares (9% of the total land area) compared to the global figure of 3.7%. Pakistan is also a signatory to international treaties on biodiversity conservation, wetland conservation, climate change, ozone protection and trade in endangered species.

Shrub forests (Dry sub-tropical broad-leaved and Dry tropical thorn forests) are the second largest forest type in Pakistan (Jan, 1993; Sheikh, 1987). These forests are managed primarily for the conservation of soil, water and wildlife resources. Past abuse, over-grazing and heavy fuelwood collection has eliminated many of the forests and degraded most of the existing ones (Sheikh, 1987). In the case of the province of the 'Punjab', where only 3.1% area is under forests, shrub forests are found over almost half of the forest area of the province. The 'Salt range' tract is the largest single compact block of shrub forests in the province (Said, 1956) and perhaps in the entire country.

1.2. RS & GIS applications in forest biodiversity conservation planning

Remote Sensing (RS) and geographic information systems (GIS) are useful tools for many forestry related applications including forest biodiversity conservation planning. Increasingly, organisations involved in forest management and conservation are using these technologies to capture and analyse spatial phenomena. In conservation biology, the focus has recently shifted from individual species to entire biomes. RS and GIS tools could be used (Noss 1990) for inventorying, monitoring and assessing terrestrial biodiversity at regional landscape and community-ecosystem levels. Gap analysis (Scott et al., 1993) is a GIS based method to identify gaps in the protection network. In a gap analysis of Western Ghats in India, Ramesh, Menon and Bawa (1997) found that several areas of high biodiversity were excluded from the highest levels of protection. Recent advancements in RS and GIS technologies have made it possible to measure forest biodiversity from satellite images.

McCormick and Folving (1998) present a list of satellite based indicators of forest biodiversity which is given in table 1-1.

Table 1-1: Satellite based indicators of Forest Biodiversity

SATELLITE-BASED INDICATORS OF FOREST BIODIVERSITY		
Component of Forest Biodiversity	**Corresponding indicator variables measurable from satellite imagery**	**Key GIS-image processing operation**
Composition	Identity, distribution and relative proportions of forest patches	Segment-based image classification
Structure	Spatial pattern (density, size, shape, etc.) of patches	Spatial analysis of image classes
Development	Temporal changes	Change detection

Source: (McCormick and Folving, 1998)

Stoms and Estes (1993) underscored the need for using remotely sensed data in the assessment of biodiversity and conservation planning. They presented a long list of potential uses, which is reproduced in table 1-2 below.

Table 1-2: Potential uses of remote sensing in biodiversity conservation

Remote Sensing information product	**Inventory patterns of richness**	**Determine biophysical factors**			**Monitor changes**
		Resource quality	**Resource quantity**	**Dynamic processes**	
Habitat type	g	g	g,e	g	g,e
Vegetation structure	a,g	a,g		g	g
Landscape geometry		g,e		g,e	g,e
Habitat fragmentation				g,e	g,e
Road density					g
DEM	g	g			
Net primary production			g,e		g,e
Actual evapotranspiration			g,e		g,e
Leaf chemistry			g,e		g,e
Biomass			g,e		g,e
Leaf Area Index			g		g

a= alpha or community scale
g= gamma or landscape scale, and
e= epsilon or regional scale

Satellite remote sensing is a widely used technique to produce land use and land cover maps and to study vegetation cover (Fung and Chan, 1994). However, owing to their peculiar characteristics such as low canopy cover and low biomass, remote sensing of shrub forests poses new challenges. The ability to remotely detect low levels of biomass is a major issue in arid and semi-arid regions. In the case of sparse canopy cover, interpretation of spectral reflectance signals is very difficult due to strong influences of bare soil background on canopy spectra (Leprieur et al., 2000; Huete, 1988). In another research study done in northern California, May, Pinder and Kroh (1997) reported that TM data were more effective than SPOT in separating shrubs from meadows, but neither TM nor SPOT data were effective in separating meadow types.

1.3. Policy issues

Over the last decade or so, a number of excellent forest and biodiversity policy documents have been prepared in Pakistan as described hereinafter. All documents realise the importance of preserving our natural resources and lay emphasis on immediate measures to address biodiversity related issues. However, regretfully, words have not been translated into actions. Time has come that these documents are followed in letter and spirit.

The Pakistan National Conservation Strategy (GOP-IUCN, 1992) acknowledges that 'true' forests or closed cover forests are very much an endangered habitat in the country. It suggests various policies and measures to mitigate the alarming situation of forest biodiversity conservation in Pakistan, of which, the important ones relevant to this study are:

1. Preserve and manage on a representative basis some old forests to maintain the bank of biodiversity.
2. Use satellite imagery in conjunction with ground truthing both to assess and monitor earth degradation processes critical ecosystems and to identify priority areas for planting (rehabilitation).
3. Preserve genetic resources and biodiversity by selective creation of strict ecological reserves, declared as such.

The current forest policy of Pakistan was prepared in 1991 (Jan, 1993). At that time about 7% of the country's land area was under protection. One of the goals of this policy is to increase the area under protection to 12% by the end of 2002. To-date, some progress has been made in this regard, however, the goal may not be fully achieved.

A 25-year period Forestry Sector Master Plan was developed in 1992 at the national level and for each province. This document (GOP, 1992) for the province of the 'Punjab' strongly emphasises the establishment of criteria and guidelines for identifying and setting aside new conservation areas on a priority basis, or enlarging existing ones. It also recommends the setting up of 7 new National Parks (NPs) in the province till 2018, up from the present 2 NPs. More specifically, it states that some areas of the 'Salt range' such as 'Tilla Jogian', 'Chinji' and 'Sodhi' must be brought into the conservation area system. The last two areas are covered in this study.

The last extensive forest survey of the 'Salt range' shrub forests was carried out more than 50 years ago (Said, 1956). It reported the existence of some remaining intact forests in the area and proposed laying out preservation plots for the future generation to know the type of the old forests. It even recommends the preservation of individual sample trees.

1.4. Problem Statement

Degradation and fragmentation of the shrub forest accompanied with loss of forest biodiversity is not a recent phenomenon. It has been going on for decades now. As far back as in the 1960s, Champion, Seth and Khattak (1965) reported that in the Kau-Phulai (*Olea ferruginea-Acacia modesta)* type in the Salt Range, repeated cutting, lopping and browsing results in the increase of less palatable and thornier species at the expense of 'Kau' and 'Phulai' which were first reduced to dense bushes and ultimately disappeared altogether. The enormous damage done to shrub forests over the years has resulted in the almost complete disappearance of Kau (*Olea ferruginea)* from the tract while *Dodonaea* species was over-exploited for fuelwood (Hussain 1999). Review of literature reveals that fuelwood collection and grazing/browsing are the two most common traditional practices going on in the forest. Hafeez and Afzal (1989) found that the population around the shrub forests seems to depend almost entirely on the state forests for their basic needs of fuelwood.

Human population growth could be considered an ultimate cause of most land use changes: however, local demographics, as well as per capita consumption and its variability, modify the effects of population (Dale and Pearson, 1997). Higher human and livestock populations that are dependent on shrub forests are, undoubtedly, the major causes of forest habitat destruction in the Salt Range (Hafeez and Afzal, 1989).

A study done by Dale and Pearson (1997) in Brazil found that highly-developed (more human influence) sites had a higher number of, though smaller in size forest patches as compared to low-developed sites, which had fewer but larger patches, and which probably supported more native species.

Measures of spatial continuity of forests and the size and shape of remaining forest fragments in the Salt range can indicate the probable condition of existing forests and the state of associated biodiversity (Kapos and Iremonger, 1998).

The last extensive forest survey of the 'Salt range' shrub forests was carried out about 50 years ago. Since then, it has not been up-dated. At present, the government forests are being managed under '*ad hoc*' yearly plans. Inspite of the lack of information about the existing state of the forest resources, the government is seriously considering a proposal to establish a large National Park in the area. This idea originated in 1997. Originally, the proposal was to reserve 340 840 hectares of government and private land for this purpose with the aim to promote ecotourism. It is pertinent to mention here that the area is quite rich in ecotourism attractions such as scenic landscape, historical sites (old temples), lakes/wetlands (including one Ramsar site) and remaining patches of old shrub forest. The idea of a large NP was shelved after it was strongly opposed by the local population, NGOs and local mining industry (The News, 1997). Subsequently, a revised proposal was put forward which set aside 62 750 hectares of government forests in a single district as the core area surrounded by a buffer zone in the private areas. However, no distinction was made between semi-natural and degraded government forests. All government forests whether in good or bad shape were included in the reserve. Howard, Viskanic and Kigenyi (1998) stress that the preferred sites within the forest for nature reserves should be the undisturbed core areas. Moreover, government forests of the adjoining districts were excluded from the National Park boundary giving the impression that the planning was not holistic.

From the foregoing discussion, it is clear that the areas, which should ultimately become a part of the NP are not being selected according to the principles of forest biodiversity conservation and reserve design. The forests of the Salt range are fast losing remaining elements of biodiversity. Already, faunal species such as panther, wolf, hyaena and perhaps Indian gazelle have vanished from the area in the last 20 years or so (Roberts, 1977). Wild plant species, especially those that are intensively exploited by the rural communities' face an immediate threat of extirpation while some may even have gone extinct.

1.5. Objectives

There are two objectives of this research study.

1. To identify suitable criteria for identifying forest remnants as priority areas for biodiversity conservation, and
2. To identify such priority areas for biodiversity conservation through the use of remote sensing and GIS.

1.6. Research questions

1. Which plant species are indicators of semi-natural forests and do these plant species occur in degraded forests as well?
2. What is the spatial distribution of semi-natural forest remnants of the area?
3. What is the degree of fragmentation of the semi-natural forests?
4. How to evaluate the conservation value of remnant forest patches?
5. Where are the gaps in habitat protection for biodiversity conservation?

2. CONCEPTS AND DEFINITIONS

2.1. Biodiversity conservation

A number of slightly different definitions of the term ‘biological diversity’ or in short ‘biodiversity’ exist in literature. According to McNeely et al. (1990), it includes all species of living organisms and the ecosystems and ecological process of which they are parts. It includes both the number and frequency of ecosystems, species, or genes in a given assemblage. WRI-IUCN-UNEP (1992) has defined biodiversity as the totality of genes, species and ecosystems in a region.

A simple, comprehensive and fully operational definition of biodiversity is unlikely to be found (Noss, 1990). He cites Franklin et al., (1981) who suggest that the three attributes of an ecosystem i.e. composition, structure and function constitute the biodiversity of an area. Composition includes species lists and measures of species diversity and genetic diversity. Structure refers to the physical organisation or pattern of a system e.g. pattern of patches in the landscape. Function involves ecological and evolutionary processes such as nutrient cycling. All the three attributes of an ecosystem are interconnected and together determine the biodiversity of an area.

Biodiversity is usually divided into three hierarchical levels: genetic diversity, species diversity and ecosystem diversity, which are measured in different ways. Genetic diversity is the sum total of genetic information contained in the genes of individual organisms. Species diversity refers to the variety of living organisms on earth. Ecosystem diversity relates to the variety of habitats, biotic communities, and ecological processes in the biosphere. Because the boundaries of communities are not exact, WRI, IUCN and UNEP (1992) term ecosystem diversity harder to measure than species or genetic diversity. Indicators of community diversity described by Reid et al. (1993) are fewer in number and in general less developed than species indicators.

The *World Conservation Strategy* (IUCN, 1980) quoted by (McNeely et al.1990), defines conservation as ‘the management of human use of the biosphere in such a way that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations’. Since biodiversity is so closely intertwined with human needs, its conservation should rightfully be considered an element of national security (WRI, IUCN and UNEP 1992).

This study involves biodiversity indicators at the ecosystem or landscape and community levels. Ecosystem diversity stands at the highest level of biodiversity. Adequate protection of an ecosystem would in-turn protect the inhabiting populations, species and their genetic diversity.

2.2. Forest Fragmentation

Habitat fragmentation is the process that occurs when a habitat or land cover type is subdivided either by a natural disturbance (e.g. fire or storm) or by human activities e.g. roads or cultivation (Dale and Pearson, 1997). The threats posed by forest loss and fragmentation to local biodiversity have been popularised for nearly two decades (Harris and Miller, 1984). Although spatial heterogeneity is a natural phenomenon, human activities are altering natural landscapes by changing the abundance and spatial pattern of habitats. The two most significant effects of forest fragmentation are a decrease in population sizes and reduction of species diversity (Zuidema, Sayer and Dijkman, 1996).

Four general types of fragmentation indices, suggested by Dale and Pearson (1997) to describe spatial patterns in habitat maps are: patch or habitat area, frequency distribution of patch sizes, measures of patch shape, and length of edge between different habitat types. Measures of spatial continuity of forests and the size and shape of remaining forest fragments are indicators of the probable condition of existing forests and the state of associated biodiversity (Kapos and Iremonger, 1998). Such measures of forest fragmentation aid in the optimal designing of forest reserves and protected areas. In this study some of the fragmentation indices such as patch size and shape will be computed to aid in identifying priority areas for biodiversity conservation.

2.3. Indicator species

Indicators are defined as measurable surrogates for environmental attributes such as biodiversity (Noss, 1990). A good indicator should be relatively easy to identify and locate in the field, give maximum information about overall conditions and should give information at the appropriate level (Dudley and Jeanrenaud, 1998). Many authors have described the use of indicator species to monitor or assess environmental conditions in ecology, forestry and other related sciences (Noss, 1990). The presence and condition of certain species have provided opportunities to make inferences on a wide array of ecological conditions (Ingram, 1992).

The flora has been largely used as an indicator of Forest biodiversity due to the following reasons as stated by Dallmeier (1998) and Reid et al. (1993).

1. Plants are easy to study because they are immobile.
2. Plants are more sensitive to environmental changes, such as hydrologic or edaphic changes, as compared to wild animals.
3. Plants, in general, have a central role in terrestrial ecosystems and also provide adequate information to interpret biodiversity indices.

4. The diversity of plants in a region does not fluctuate over short time intervals.
5. Data on plants is often available or easier to collect.
6. Areas with high plant species richness tend to have high species richness in other groups.

Inspite of their immense utility, indicator species must be used with caution as they sometimes give little or misleading information about overall environmental trends and attributes. In this study, rare, invasive and climax phase indicator plant species of shrub forests of the area have been selected from existing literature (Sheikh, 1993; Sheikh, 1987; Champion et al., 1965; WCMC, 1991; Said, 1956) and in consultation with a local expert of forest ecology (Dr. Mirza Hakim Khan of Pakistan Forest Institute, Peshawar, Pakistan).

2.4. Natural and semi-natural forest

Forest naturalness is characterised by elements such as a complex spatial structure, a composition and distribution of climax species, a wide range of ages in tree species and the presence of coarse woody debris. All of the following loosely defined terms i.e. ‘natural’ forest, ‘old-growth’ forest, ‘ancient’ forest, ‘virgin’ forest and ‘primary’ forest have been used interchangeably in literature (FAO, 1997). The same document defines ‘semi-natural forests’ as those forests, which have been modified by humans through use and management.

Natural forests have unique features that distinguish it from other forest types. A more natural forest is one that is only slightly modified, contains primarily native species and requires less human input to maintain system functions (Peck, 1998).

In this study, the term ‘semi-natural forest’ as defined by FAO (1997) has been used to describe the remaining forests of the study area. Prior to 1980, disturbance was common before a ban on commercial timber harvesting was imposed (GOP, 1980). Average stand age of most of the remaining forests is between 50 to 100 years. Only when these forests mature sufficiently for some of the old trees to die and fall down, could they be termed as old-growth forest (Al and Kuiper, 2000). At the moment, some of the remaining forest fragments have a dense, closed canopy. Such forests could evolve into natural forests if continued protection is afforded. However, slight disturbances would be required to create gaps in the dense forest canopy if more natural woodland is to be desired.

2.5. Reserve design

Reserves or protected areas are designed according to some principles of reserve design. The purpose is to preserve biodiversity by regulating the human use of the area in such a way that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.

The elements of reserve design include core areas, corridors, buffers and matrix (Peck, 1998). An example of a simple reserve design is presented in Fig. 2-1. A core zone is a strictly protected central area representing typical samples of natural or less disturbed areas while Buffer zone(s) surround the core zone and serve to protect the important core area. This zone is not strictly protected allowing activities such as research, education, ecotourism and ecological farming that are compatible with the protection of core zone. Corridor is an area, usually narrow in width that connects individual core areas. The purpose is to support the movement of specific species, as well as other important ecological processes. A matrix is that vegetation and ecosystem which is most connected and which touches most other habitat types in an area e.g. forest, woodland, grassland, or agriculture (Forman and Godron, 1986). Cores, buffers and corridors are embedded in the landscape matrix. The objective of this study is limited to the identification of core areas.

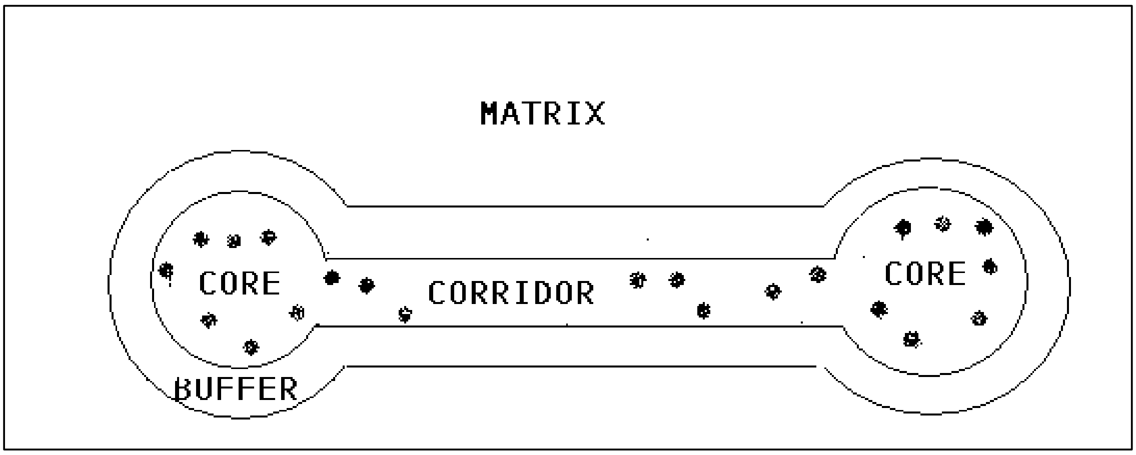


Figure 2-1: A simple diagram of a reserve with two core zones

2.6. Remote sensing

2.6.1. A brief overview

Remote sensing is the technique of obtaining information about an object or feature through the analysis of data acquired by a device that is not in contact with the object or feature under investigation (Lillesand and Kiefer, 2000).

Normally data about earth's features is acquired either from air (aerial photography) or from space (satellite imagery). Aerial photographs are in analogue form while images are basically in digital form. Remote sensing is based on the measurement of electromagnetic energy. The remote sensing sensor measures the energy that is reflected or backscattered by the earth's surface. The measured energy is converted and stored as a digital number (DN) value, which ranges from 0-255. Each pixel (picture element or unit area or ground cell) has a single DN value. Most sensors measure reflected sunlight

however, some sensors detect energy emitted by the earth itself or provide their own source of energy (active remote sensing).

The reflective characteristics of vegetation are different from those of bare soil or water (Mather, 1999) and are dependent on the properties of the leaves including the orientation and the structure of the leaf canopy. Figure 2-2 shows the typical spectral reflectance curves for vegetation, bare soil surface and clear water. The proportion of the radiation which is reflected in the different parts of the spectrum depends on leaf pigmentation, leaf thickness and composition (cell structure) and on the amount of free water in the leaf tissue. In the visible portion of the electromagnetic spectrum, the reflectance from red light is comparatively low since it is mainly absorbed by chlorophyll for photosynthesis. The reflectance in the near infrared band is the highest but the amount is proportional to the cell structure of the leaves.

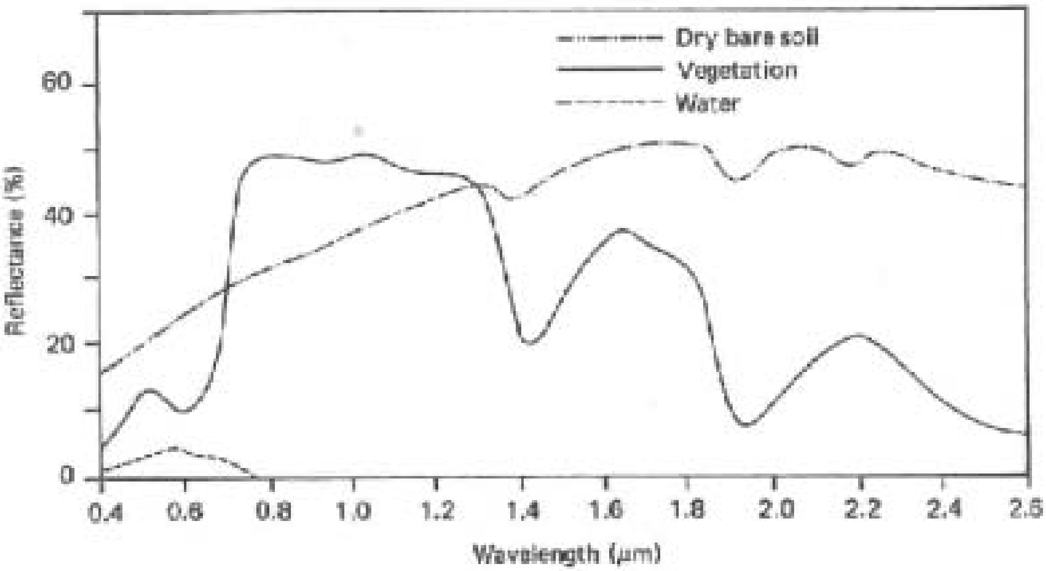


Figure 2-2: Typical spectral reflectance curves for vegetation, soil, and water.
(source: Lillesand and Kiefer, 2000)

Visual or digital (computer based) image-interpretation techniques are applied to extract information from image data. For an accurate image classification, data collected from ‘ground truthing’ or ground survey is linked to image data. In this way a map showing various land cover types of the area is produced. This study uses satellite imagery to detect and map a forest community by taking advantage of unique reflective characteristics of forest vegetation.

2.6.2. Vegetation indices

Vegetation indices are quantitative measurements indicating the vigour of vegetation. They show better sensitivity than individual spectral bands for the detection of biomass and other vegetation characteristics. Their usefulness lies as an aid to remote sensing interpretation, the detection of land use changes, the evaluation of vegetative cover density, forestry, crop discrimination, and crop production (Bannari et al., 1995). Red and near infrared channels of the sensors on board satellites are particularly well suited to the study of vegetation (Mather, 1999). Several vegetation indices have been developed of which, NDVI (Normalised Difference Vegetation Index) is still the most widely used one despite the development of many new indices that take into account soil behaviour (Bannari et al., 1995; Groten, Immerzeel and Leeuwen, 1999). In this study, NDVI has been used to differentiate vegetation from other land cover classes and also to differentiate forest vegetation types. Theoretically NDVI value ranges between –1 to +1. Actually measured value range from –0.35 (water) through zero (soil) to +0.6 (dense green vegetation). Vegetation cover can be compared between different soil types at NDVI values of 0.05 or higher (Groten, Immerzeel and Leeuwen, 1999). This corresponds to a DN value of 135 or higher after the NDVI image has been re-scaled to the image domain (0-255). It can be concluded that the more positive the NDVI the more green vegetation there is within a pixel. Mathematical formulae for calculating NDVI and re-scaled NDVI are given below.

$$NDVI = \frac{NIR - R}{NIR + R}$$ *NIR = near infra red band* *R = red band*

$$\textit{Re-scaled}\ NDVI = \frac{NIR - R}{NIR + R} \times 127 + 128$$

In the case of Landsat Thematic Mapper remote sensing data, the formula is

$$NDVI = \frac{TM4 - TM3}{TM4 + TM3}$$ *TM4 = near infra red band* *TM3 = red band*

2.7. Conceptual Framework

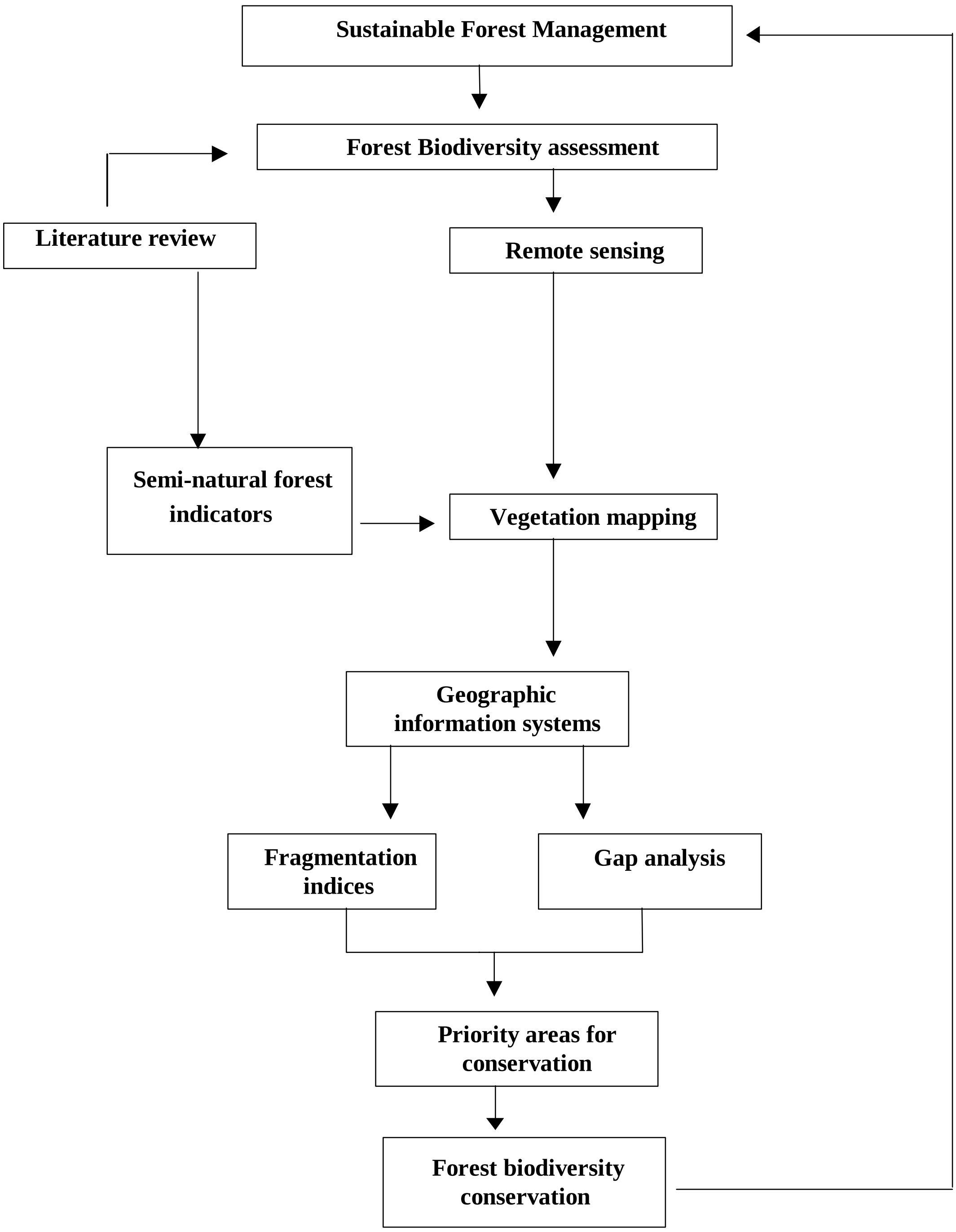


Figure 2-3: Flowchart of conceptual framework

3. METHODS AND MATERIALS

3.1. Selection of Study area

The objectives of this research required that the study area should have the following features:

1. Shrub forest type.
2. Forest biodiversity under threat.
3. Sufficiently large size to justify the use of satellite imagery.
4. Accessibility, and
5. Availability of recently acquired remote sensing data and topographic map.

To meet the above-mentioned requirements, the Salt range area in Pakistan was selected as it fulfilled almost all the conditions. However, a large scale and recent topographic map of the area was not available but this is normal for any geographical area in Pakistan as it is difficult to obtain a topographic map due to security restrictions.

3.1.1. Location of the Salt range

The study area selected for this study is called the Salt range which is located in the central-north region of the province of Punjab in Pakistan (see map in fig. 3-1 and a photo in fig. 3-2). It is situated mainly in the districts of ‘Chakwal’ and ‘Khushab’ with the larger part in the former. In the east-west direction these low hills extend for over 130 kilometres and about 50 kilometres in the north-south direction. A large part, but not all of the Salt range is covered in this study. Parts in the extreme east and west portions and some parts in the Southwest portion have been left out due to military restrictions and cloud cover on the satellite image, respectively. Cloud covered part of the imagery was removed using visual interpretation methods. If a rectangular block of the area is cut out, then the study area lies between 72^0 E to 73^0-6′-57″ E longitude and between 32^0 -31′-6″ N to 32^0 -51′ -21″ N latitude. Study area is over 2300 square kilometres in size.

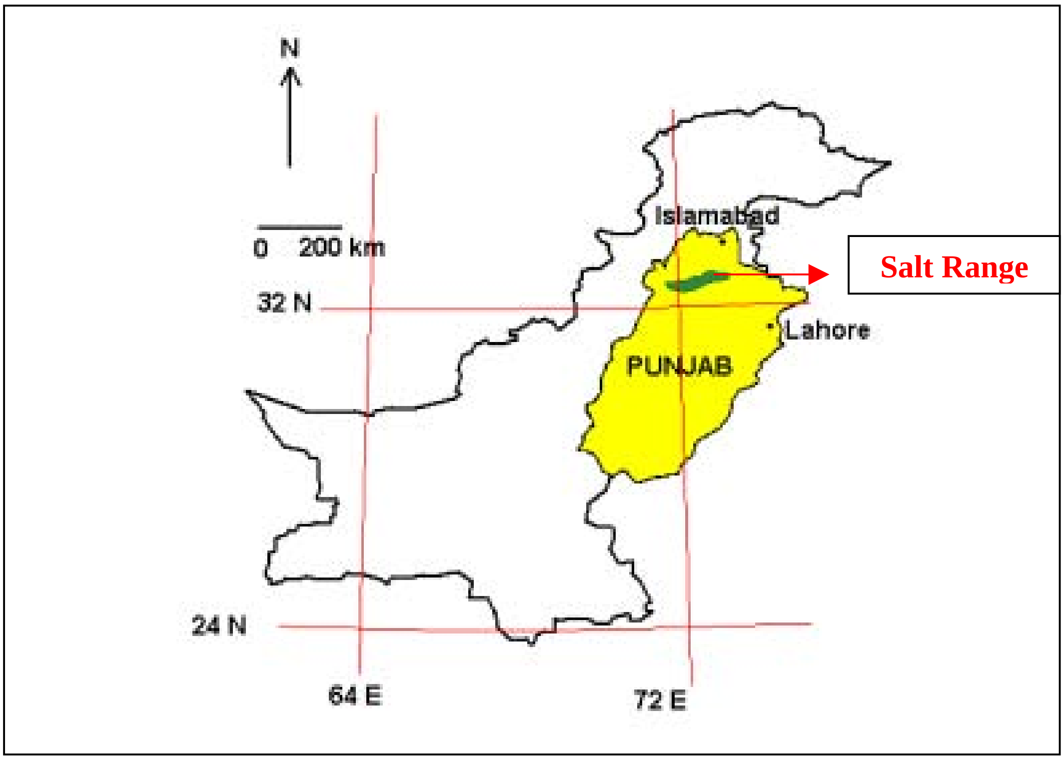


Figure 3-1: Map of Pakistan showing location of study area (Salt range)

Figure 3-2: A photo showing forest landscape of the area

3.1.2. Climate

The climate is one of extremes. In winter it is very cold, sometimes the temperature goes below the freezing point and in summer it is very hot. Hot winds blow in summer. Mean maximum daily temperature is above 40^0C in June. July and August are the rainiest months (monsoon showers) and some rainfall is also received in January and February but the rainfall in general is erratic often coming in a few storms. The average annual amount of rainfall decreases from east to west, resultantly, the vegetation is more luxuriant in eastern part than in the west (Said, 1956). This fact is confirmed by table 3-1 which gives average annual rainfall data (1985-1995) for three towns that are situated in the east, centre and west of the Salt range tract, respectively.

Table 3-1: Mean annual rainfall data for the Salt range

TOWN	Location with respect to the Salt range	Mean annual rainfall (1985-95)
Jhelum	East	948 mm
Chakwal	Centre	740 mm
Mianwali	West	592 mm

(Source: Computer section-RMC, Lahore, 1999)

3.1.3. Forests

Sheikh (1987) and Champion, Seth and Khattak (1965) have classified salt range forests as dry sub-tropical broad-leaved forests. Said (1956) refers to them as dry deciduous scrub forests. The government manages approximately 68 000 hectares of the forests in the proper Salt range tract as defined by Said (1956). This amounts to over 10% of the total forest area (630 000 ha) of the Punjab province (Jan, 1993). The largest compact block of sub-tropical shrub forests in the entire province, if not in the entire country, is found here.

Although not dry forests in the real sense, due to poor site conditions and erratic rainfall, these forests have become more or less semi-arid forests. These are low forests of branchy trees, varying in density from complete closure under the most favourable conditions to scattered single trees or groups on drier sites with a fair amount of shrub growth. Trees of large dimensions may be seen in valleys and gullies where deep soils and some moisture are available. The main tree and shrub (non-woody) species are *Olea ferruginea, Acacia modesta, Pistacia integerrima, Dodonaea viscosa, Capparis aphylla, Tecoma undulata, Gymnosporia royleana, Monotheca buxifolia* and *Zizyphus nummularia* (Sheikh, 1987 and 1993; Said, 1956). Most of the plant species are found through out the area (GOP(a), 2000). *Olea ferruginea, Acacia modesta* and other species generally occur in mixture (Said, 1956). Natural vegetation of *Olea ferruginea* is absent almost everywhere and that of *Acacia modesta* is not common. Most of the forests lie between 450m to 900m elevations. A few peaks are above 1200m. All aspects are present. Generally, *Olea ferruginea* occurs on cooler northern aspects and sheltered places with some *Acacia modesta*. On hotter southern aspects *Acacia modesta* is the principal tree species where *Olea ferruginea* may be found scattered and in sheltered places (Said, 1956; Sheikh, 1987). Both the main tree species i.e. *Olea ferruginea* and *Acacia modesta* are slow growing. *Olea ferruginea* attains a height of about 3 meters in 30 years and *Acacia modesta* reaches about 3.5 meters height at this age (Said, 1956). Under good site conditions a fully mature *Acacia modesta* tree can grow up to 9 m in height and a mature *Olea ferruginea* tree up to 9-12m tall (Sheikh, 1993).

3.1.4. Forest Management

The forests were demarcated, recorded and settled for the first time in 1880s and 1890s (Said, 1956). Legally the government forests are classified as 'reserved' or 'unclassed' forests. There are three full-fledged administrative divisions of the provincial forest department responsible for managing the government-controlled forests of the area. The Mineral Development Corporation manages some forest areas (area statistics not available) while local people look after small community forests scattered all over the tract (area statistics not available).

Ever since the government forests were constituted in the late nineteenth century, no forest management plan was prepared until 1952 when Said (1956) wrote the first plan. The shrub forests provide valuable protective cover to the watersheds and are a source of firewood and fodder to the local communities. The main management objective in the government-controlled forests is to protect the watersheds and at the same time produce some fuelwood. Prior to 1980 when a complete ban was imposed on commercial fellings (GOP, 1980), these forests were worked under the selection coppice system with exploitable diameter of 15-20 cm, 20 cm and 5-7 cm for *Olea ferruginea, Acacia modesta* and *Dodonaea viscosa* respectively.

Past abuse, overgrazing and heavy firewood extraction have eliminated many of the forests and degraded most of the existing ones (Sheikh, 1987). The requirements of the people which include grazing for their cattle, sheep, goats and camels; firewood for heating and cooking; small timber for agricultural implements and for building purposes are met with from these forests. People have rights to graze their cattle and collect firewood (dry and dead). Grass cutting is also generally allowed. Lopping is not permitted anywhere. However, illicit lopping and felling are common (Said, 1956; Sheikh, 1987).

3.1.5. Biodiversity

The Salt range is a biodiversity 'hotspot' in the sense that it is a unique but threatened natural forest habitat, surrounded on all sides by cultivated area. In Pakistan's National strategy for GEF (global environment facility), the Salt range is identified as a hotspot based on documents such as the Pakistan Biodiversity Action Plan (WWF-IUCN-GOP, 1995 ?), and works of Roberts (1977 and 1991).

According to Roberts (1977), small and scattered populations of the following mammal species still inhabit the Salt range: Urial (*Ovis vignei punjabiensis*), Red fox, small Indian mongoose, Caracal, jackal and perhaps Chinkara (*Gazella gazella bennetti*). Some other large wildlife species such as panther, wolf, and hyaena used to occur in the not too distant past.

Among bird species, partridges are common, particularly the grey partridge, the rock partridge and the see-see partridge. Common quail is found in some areas (Roberts, 1991) and wild peafowl occur in the Kallar Kahar area. The wetlands of the Salt range are wintering grounds for many migratory bird species coming from Central Asia. One of the wetlands (Khabbeki, 283 ha) is a designated ‘Ramsar’ site.

The flora includes the common plant species mentioned earlier. Many more plant species are also found in the area but in low numbers. Local communities use several medicinal plant species. A detailed survey of the plant wealth of the area is however, lacking.

To protect biodiversity there are five protected areas (WCMC, 1991; Jan, 1993) in the tract at present. These are Chinji National Park (6 095 ha), Chumbi Surla wildlife sanctuary (55 945 ha), Sodhi wildlife sanctuary (5 820 ha), Diljabba-Domeli game reserve (118 106 ha) and Khabbeki lake wildlife sanctuary (283 ha). Except for the game reserve, the rest of the protected areas are included in the study area.

3.1.6. Topography, Geology, Soils and Drainage

The general characteristic formation of the Salt range is that it consists of two distinct hills running parallel to each other in a general east–west direction. The rock consists of sandstone and limestone scattered over the entire area. The sandstone is laminated white or cream coloured, dark red or purple brown. Limestone occurs in pure, laminated and compact forms generally in the higher reaches. Salt layers generally lie at the lowest level but exposed at some places. On the southern side strata of gypseous red-marl are greatly exposed. The area is rich in minerals like salt, coal, lime, different kinds of clay and gypsum (Said, 1956). Hundreds of mine operate in the area. Local mining industry is one of the strongest opponents of forest conservation in the area (The News, 1997).

The topsoil has been practically washed away. Erosion has reached a very advanced stage in some parts and bare rock has been exposed which can not support any kind of vegetation. Generally speaking the area is badly cut into ravines. Rocks and boulders are a common feature. Gradients vary greatly and are generally steep. The surface configuration is almost everywhere very irregular and rugged (Sheikh, 1987; Said, 1956).

The surplus drainage from the surrounding hills collects in low-lying areas forming lakes namely, Uchali (approx. 800 ha), Khabbeki (283 ha), Jhalar (approx. 100 ha) and Kallar Kahar (approx. 100 ha). The main streams are Bunha, Sauj, Drabi and Gambir (GOP(a), 2000). After every rain shower, the rainwater runs rapidly off the slopes swelling the streams. Excepting a few these streams are generally dry in summer and winter.

3.1.7. Land use, human and livestock population statistics

Important towns of the area are Chakwal, Choa Saidan Shah, Kallar Kahar, and Nowshera. Subsistence farming is the main occupation of the people of the area (GOP(a), 2000). Land holdings are small. Crop production depends on rainfall. The main crops are wheat, groundnut, lentils and grams. Livestock rearing is also common (GOP(b), 2000). Orchards are raised in some areas such as Kallar Kahar and Choa Saidan Shah. Locquat is the major fruit tree raised in these orchards.

Current statistics of human and livestock populations of the two districts of the Salt range are given in table 3-2 below:

Table 3-2: Human and Livestock population statistics

DISTRICT	POP. (1998)	DENSITY Per square km	LIVESTOCK POP. 1999			
			cattle	buffalo	sheep	goats
Chakwal	1 083 725	166	274 287	99 996	125 309	377 616
Khushab	905 711	139	217 206	117 996	180 430	393 790

Source: (GOP(a), 2000 and GOP(b), 2000)

3.2. Choice of methods

Keeping in view the objective and research questions, literature was consulted to select appropriate and relevant research methods for this study. Review of literature revealed that the following methods were applicable:

1. Gap analysis

Scott et al. (1993) developed the gap analysis technique. It is a rapid and efficient method for conservation evaluation of large areas functioning as a preliminary step for the more detailed studies needed to establish actual boundaries for potential biodiversity management areas (Scott et al., 1993). Gap analysis assesses the degree to which natural communities and vertebrate wildlife are represented in lands managed for conservation. Managers and planners benefit from this through the identification of unprotected 'gaps' in the conservation network. The first step in gap analysis is to develop a map of dominant vegetation types based usually on Landsat Thematic Mapper satellite images. If needed, a predicted vertebrate distribution map is then created using wildlife habitat relationship models. Categories of land management, ranked by varying levels of protection, form an additional GIS layer. This layer is developed from existing database on land-use and ownership. These three data sets comprise the basic elements of a gap analysis. A GIS layer of threatened, endangered or rare species could be added to the three datasets, if required (Peck, 1998).

Gap analysis technique has been used partly in this study, as the main focus of this study was flora, whereas in gap analysis both flora and fauna, especially the distribution of vertebrate animals, are taken into account. Information is lacking about the wildlife habitat relationship models for the major vertebrate animals of the study area. Vegetation is usually considered the most important component of an animals environment (Riney, 1982). The conservation of the vegetation of the area is expected to sustain associated wildlife as well. Moreover, land use and ownership information is an important requirement in gap analysis. For the Salt range, such information was however, not complete in all respects. For the purposes of this study, methods of gap analysis were applied to obtain the following products:

1. Map of remaining semi-natural forests based on TM satellite image.
2. Digitised map of existing protected areas, and
3. Digitised map of land ownership i.e. government controlled forests. All areas falling outside government controlled forests were considered to be private lands.

2. Rapid Assessment Program (RAP)

Developed by Conservation International in 1989, RAP assembles teams of world-renowned experts and host country scientists to generate first-cut assessments of the biological value of poorly known areas. An area's importance can be characterised by its total biodiversity, its degree of endemism, the uniqueness of an ecosystem, and the degree of risk of extinction (Parker et al., 1993).

Satellite images, if available, are inspected prior to a field trip to determine the extent of forest cover and likely areas for exploration. Points for field transects are identified from an aerial survey. A trip lasts from two to eight weeks.

Transects (usually 0.1 ha in area, 50 by 20 meters in dimension) are laid in major habitat types to estimate plant species richness and degree of endemism (Parker et al., 1993). In addition, bird, mammal, reptile and amphibian species survey is also carried out with the aim to identify areas rich in biodiversity for subsequent conservation measures.

Few core concepts of RAP as related to rapid vegetation survey have a relevance to this study. These are, for example, the use of satellite imagery for identifying likely areas for exploration and rapid biodiversity appraisal of a previously unexplored area undertaken in a short period of few weeks. Ideally, a RAP should cover all aspects of an area's biodiversity e.g. plants, animals and habitats which is only possible if the RAP team comprises of experts from all disciplines which was not so, in this study. In this study, a satellite image of the area was used to identify candidate forest areas for field data collection.

3.3. Site selection for field data collection

First of all, the study area was identified on an un-georeferenced satellite image of the area with the help of a coarse-scale topographic map of the area combined with expert knowledge. Using ILWIS, a sub-set of the scene was cut that covered the entire study area. Rough boundaries of the study area were then digitised on screen using expert knowledge and by taking help from the topographic map. This image could not be georeferenced before fieldwork due to the non-availability of a large scale topographic map.

Landsat ETM+ (Enhanced Thematic Mapper) satellite image of the study area taken on the 14th of July 1999 was used in this study. Fieldwork was carried out in August 2000 i.e. in the same season and just one-year after the acquisition of digital data. Therefore, both the data sets are more or less compatible and up-to-date.

In the Salt range area, rainy season usually commences at the end of June, which brings the vegetation back to life. In July and August, the vegetation is at its peak. There is greenery everywhere and biomass production is at its highest. This is the best season for acquiring digital data for the purposes of forest vegetation discrimination, as most of the farmlands are crop less during summer season, except those near the lakes that use ground water for irrigation.

Using the equation given in 2.6.2, an NDVI map of the study area was produced. Thereafter, aggregate map operation in ILWIS 2.1 (1997) was applied to the NDVI image. It aggregated blocks of nine input pixels by averaging the values. This was done to consolidate and highlight areas with higher NDVI values in order to facilitate the delineation of forest fragments on the image through screen digitising. Forest areas supposedly have higher NDVI values due to their greater green biomass.

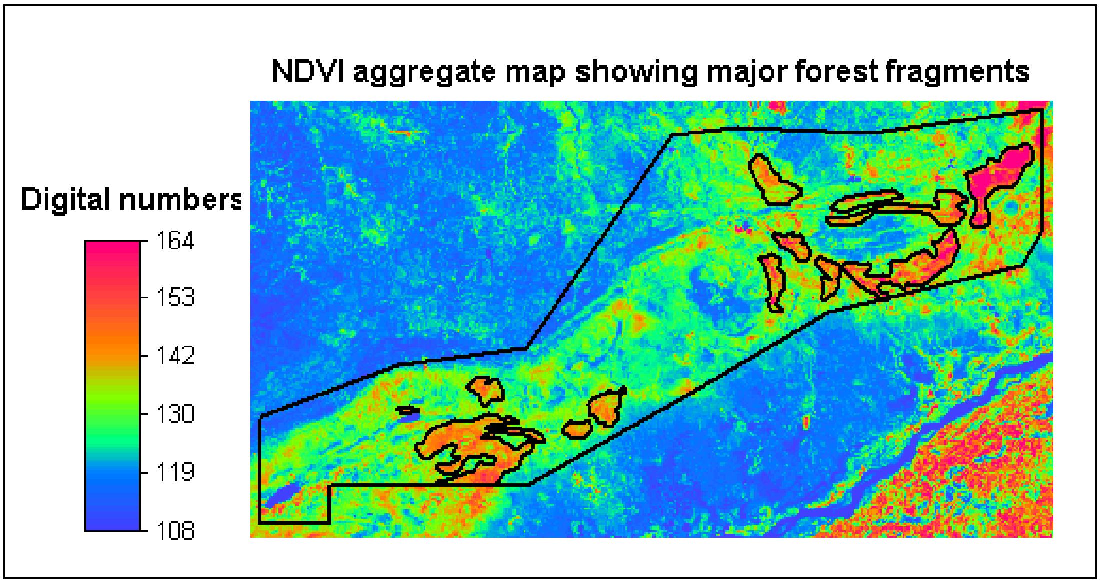


Figure 3-3: Identified major forest areas in the Salt range for fieldwork

In the resultant NDVI map, pixel digital number (DN) ranged from 0 to 255. Applying Groten, Immerzeel and Leeuwen (1999) rule (please refer to 2.6.2), pixels with DN greater than 135 that appear red in colour supposedly indicate higher green biomass, which could either be a forest or a cultivated land or an orchard. DN values less than 135 indicate water bodies, bare soil or degraded grassland. Local knowledge of the study area combined with visual interpretation of false colour composite (FCC) image were used to differentiate cultivated areas or orchards from natural vegetation so that only forest areas were picked. A total of 13 major forest areas were identified on the imagery as shown in figure 3-3.

The false colour composite image was prepared using bands 4,3 and 2 to aid in visual interpretation (ILWIS 2.1, 1997) of various land cover types on the ground. Red colour was assigned to the near-infrared band (TM4), green colour to the red visible band (TM3) and blue colour to the green visible band (TM2). Green vegetation appeared reddish on the image. Various visual image interpretation techniques namely colour tone/hue; texture; shape; size; pattern; site and association were used in this interpretation exercise. Both the NDVI aggregate map and FCC were inspected before delineating the major forest areas on the image.

3.4. Field data collection

Field inventory form (appendix 1) was developed according to vegetation description and analysis methods described by Kent and Coker (1992). As this study is a kind of rapid biodiversity appraisal, therefore, those data collection methods that were relatively quick and easy to apply were selected. Moreover a suitable sampling design, sample size, plot shape and size, and the use of Chi-square statistical analysis for qualitative vegetation data were also selected, on the basis of this document.

3.4.1. Sampling design

The choice of a sampling design depends upon the aims and objectives of the study, available time and resources, type of habitat and proposed methods of data analysis and presentation (Kent and Coker, 1992). Before deciding as to which sampling design was appropriate for this study, the following points were considered: size of the study area, time available for field work, nature of terrain, weather, and the availability of a topographic map and geo-referenced satellite image. Random or stratified random sampling designs could not be applied in this study due to the lack of information about the basic characteristics of the area, which is a must for stratification (Kent and Coker, 1992). Secondly and more importantly, a large-scale topographic map and a geo-referenced satellite image of the area were not available during fieldwork phase. Without a geo-referenced image and topographic map, it is not possible to mark random points on the image, which could then be identified correctly on the ground. Keeping in view the above constraints it was deemed fit to adopt systematic sampling design for this study which involves the location of sample plots at regular intervals (Kent and Coker, 1992). The idea was to first identify suitable forest areas on the satellite image and then visit such areas for detailed field data collection through line transect survey. This was considered to be a good solution to the problem of non-availability of a topographic map and geo-referenced image. Later on, after the fieldwork was over, a geo-referenced and atmospherically corrected copy of the same imagery was luckily obtained from WWF-Pakistan. The geo-referenced image was then used in further processing of the remote sensing data.

Line transect is a form of systematic sampling design. This approach is very popular in vegetation surveys (Kent and Coker, 1992). In this approach samples of vegetation characteristics are taken along a transect line. The first sample plot is located at random and subsequent sample plots are laid out at fixed intervals.

In this study transects were laid out either in gullies, considered a unique habitat or in areas selected in the field as being representative of the environmental variability so as to cover variation in site conditions. There was no fixed standard for a gully. Some gullies were very wide, while others were narrower than 5 meters. Another advantage of gully transects was that they were highly accessible, easy to manage and less time consuming. In contrast, non-gully transects were comparatively harder to manage because of the difficult terrain (please see photo in figure 3-2), low accessibility and lack of shade from the burning sun. Non-gully transects were aimed at covering maximum elevation gradient, slope classes, aspects and forest edge and interior.

Prior to the commencement of fieldwork a short reconnaissance survey was undertaken to get an overview of the forest patches. The initial plan was to have two transects in each forest patch but time constraint and accessibility problems did not allow this. Some of the forest patches were found to be located in remote areas, which were not visited during the data collection phase. Out of the 13 larger forest areas that were initially identified for field data collection, 8 were visited during fieldwork. Table 3-3 gives the detail of the number of transects taken in the study area.

Table 3-3: Number of line transects taken during fieldwork

TYPE OF TRANSECT		TOTAL
GULLY	NON-GULLY	
6	7	13

There was no hard rule about the actual starting point of a transect. All we had to be sure of was that we were within the forest patch as identified on the image. A hard copy of the map given in figure 3-3 was taken to the field. Besides, a laptop computer and a small scale topographic map of the area were also at hand which were used as a guide in identifying and locating remotely sensed forest patches on the ground. In all cases, the first sample plot on the transect was taken at least 250 meters away from the road to eliminate any kind of road related disturbance effect. Subsequent sample plots were taken every 250 meters. The total length of a transect varied from place to place depending on the terrain and size of the forest patch. The shortest transects had 4 sample plots while the longest transect had 10 sample plots.

3.4.2. Sample size and distribution

The sample size required in any study is determined by the objective of the study, the resources available, type of study, variability of the characteristic to be measured, the precision required and the required confidence that the precision is valid (Kaewsonthi and Harding, 1992). Time was a major limiting factor in this study. In all 84 sample plots were measured on the 13 line transects. One of the plots fell in an orchard and was therefore discarded. The rest of the 83 plots were located within forest areas.

3.4.3. Plot size and shape

Circular plots of 450 square meters size, which gives a radius of 11.97 meters or roughly 12 meters for the plot, were used in this study. The reason for selecting this shape was that it was easy and quick to lay out in the field as compared to a square or rectangular shape. Plot size was chosen from Kent and Coker (1992) who have suggested a range of plot sizes for different vegetation types. For woodland canopies they suggest a minimum sample size of 400 square meters. For a circular plot it gives a radius of 11.28 meters. In order to avoid decimal numbers, the radius of 12 meters was selected. This radius gives a diameter of 24 meters for the plot, which is fairly compatible with the TM pixel size of 30 x 30 meters.

3.4.4 Data collection within sample plot

Field data were collected from within sample plots and in-between sample plots along the transect line (specimen inventory form is given in appendix 1).

The following types of measurements were recorded in sample plots. Field data was divided into three classes namely, locational and environmental data, biological data, and disturbance data.

GPS reading

A Garmin 12 XL GPS (global positioning system) device was used to record co-ordinates of centre of sample plot in WGS-84 datum. These data were subsequently converted into LCC (Lambert Conformal Conic) projection system to make it compatible for use with the geo-referenced satellite imagery. Conversion was done in Erdas Imagine 8.4 (1999).

Slope

Slope was measured in percent with the help of a clinometer. The main purpose of measuring slope was to determine the plot's radius. Slope correction is necessary in circular plot lay-out as on slopes the shape is no longer circular. The formula for calculating plot radius on sloping surface was taken from de Gier (1992). Only 3 slope classes were formed, 0-25%, 26-75% and > 75%. Plot radii 12m, 13m, and 14.5m were used for the three slope classes respectively.

Plot radius and distance in-between plots

An ordinary 30-meter long measuring tape was used to measure sample plot radius and distance between sample plots. Sometimes, distances between plots were measured by counting the number of steps in situations where it was not possible to use the tape because of thick shrub cover or terrain variations. It was established from few checks that 4 normal steps on flat ground were roughly equal to 3 meters. For sloping areas, the number of steps was multiplied by a factor depending on the slope percent. The calculated factors were 1, 1.07, 1.25 and 1.5 for general slopes 0-25%, 26-50%, 51-100% and >100% respectively. The formula is: factor = 1/Cosec(Tan^{-1} (Slope in %)).

Altitude

Plots altitude was recorded in meters with the help of an altimeter. The altimeter was regularly calibrated from a point of known elevation in the study area.

Aspect

Aspect is the direction, towards which a slope faces. There are eight possible directions; north, south, west, east, north-east, north-west, south-west, and south-east. Flat areas have no aspect. Aspects of the plots were determined with the help of a compass.

Mean plot tree height

Forests of the study area are low forests. Maximum tree height is 9-12 meters (Sheikh, 1993). Such low tree heights can be estimated without using a height-measuring instrument. In order to speed up the data collection work, it was decided to have three height classes i.e. up to 3m, 3-6m, and over 6m. Mean plot tree height was estimated ocularly. A 3m long stick was made in the field. The stick was fixed in the ground at 5 points inside the plot. These points were: centre of the plot and the plot boundary marks in the four directions. Thus, there were five estimated height class readings for each plot. The height class that had the highest frequency of readings represented the mean plot tree height of the plot. In the case of a tally between 2 classes, an overall view of the plot tree heights was taken to assign it to a particular tree height class.

Plot tree and shrub canopy cover

Cover is defined as the area of ground within a plot which is occupied by the above-ground parts of each species when viewed from above (Kent and Coker, 1992). Plot tree and shrub canopy covers were estimated visually by moving around in the plot and recording the appropriate canopy cover class as a percentage using five classes according to the Braun-Blanquet scale (Kent and Coker, 1992). The five classes were: less than 5%, 5-25%, 26-50%, 51-75%, and 76-100%.

Presence of plant species of the climax phase

The climax plant species of the area were selected by consulting literature (Sheikh, 1993; Sheikh, 1987; Champion et al., 1965; WCMC, 1991; Said, 1956) and in consultation with Dr. Mirza Hakim Khan (Forest Ecology expert of Pakistan Forest Institute, Peshawar, Pakistan). These species are: *Olea ferruginea*, *Acacia modesta*, *Dodonaea viscosa*, and *Gymnosporia royleana.* The first two are trees while the last two are shrubs. The presence of these plant species in any form or size (height > 0.5 m for tree species) within the sample plots was recorded in the inventory form. The number of specimen of both the tree species was also counted in each plot.

Presence of rare plant species

Rare plant species of the area were identified from Sheikh (1993) and in consultation with Dr. Mirza Hakim Khan (Forest Ecology expert of Pakistan Forest Institute, Peshawar, Pakistan). These plant species are: *Pistacia integerrima*, *Tecoma undulata*, and *Monotheca buxifolia.* The first two are tree species while the last one is a shrub. Their presence in any form or size within the sample plots was recorded in the inventory form. The number of specimen of both the tree species was also counted in each plot.

Presence of regeneration of climax tree species

Presence of regeneration (< 0.5m in height) of *Olea ferruginea* and *Acacia modesta* was recorded for each sample plot.

Presence of invasive plant species

Prosopis juliflora (tree) and *Adhatoda vasica* (shrub) are the main invasive forest plant species of the area (Sheikh, 1993; Champion, Seth and Khattak, 1965). Their presence in any form or size within the sample plots was recorded in the inventory form.

Other disturbance data (grazing, soil erosion, wood debris on ground, signs of fire, and signs of fresh lopping or stumps)

Disturbance data involved the estimation of degree of human disturbance within the plot. Indicators of human disturbance included: signs of fire, grazing traces, degree of soil erosion, occurrence of invasive plant species, left over parts of plants on forest floor, presence of fresh stumps and signs of fresh lopping (Acharya, 1999; Sheikh, 1993). Table 3-4 gives the details of the type of measurements made to collect disturbance data in each plot.

Table 3-4: Disturbance indicators and verifiers

INDICATOR	CLASSIFICATION	Verifiers used in classification
Grazing pressure	low, medium or high	1. Livestock droppings 2. Livestock presence in or around plot 3. Signs of grass cutting or lack of grass
Soil erosion	low, medium or high	1. Exposed tree/shrub roots 2. Gully formation 3. Stony ground surface
Wood debris	low, medium or high	Amount and sizes present in proportion to number of trees in the plot
Invasive plants	present or absent	Present means if both *Prosopis juliflora* and *Adhatoda vasica* were found in plot
Signs of fire	present or absent	Burnt stems or ash on ground
Signs of fresh lopping/stumps	present or absent	Signs of branch cutting or removal of trees by axe or saw, or the presence of green parts

The degree of disturbance of a plot was categorised into qualitative classes by subjective methods. A sample plot was classified as belonging to high grazing pressure class if livestock presence and/or livestock droppings were observed inside the plot. In case, livestock was observed in the vicinity of a plot and/or there were signs of grass cutting or complete lack of grass cover within the plot, that plot was classified as having medium grazing pressure. Low grazing pressure means if none of the above verifiers used in estimating the degree of grazing pressure was observed in the plot.

In the case of soil erosion, a plot's degree of soil erosion was rated as high if both of the first two verifiers were observed. If one of the three verifiers was mainly observed, the rating was medium, otherwise low.

Regarding the estimation of wood debris (dead, dry wood) in a plot, the number and dimensions of trees was kept in view. If thick and long branches were observed lying on the ground, the rating was high. If small and thin parts were seen, the rating was medium, otherwise low.

3.4.5. Data collection in-between sample plots

While moving from plot to plot on the transect, some recordings were also made along the way. Occurrence of any rare or exceptionally large indicator tree species, seen by naked eye on either side of the transect line within approximately 50 meters distance was recorded. However, GPS was not used to record the exact location of the target. This data was used to construct a GIS layer of rare species locations.

3.4.6. Secondary data collection

The following types of secondary data were collected from various offices in the study area for use in this study:

1. Map showing boundaries of government controlled forests.
2. Map of protected areas.
3. Map of major roads in the area.

ILWIS 2.1 (1997) was used to digitise the relevant parts of the above maps.

3.4.7. Organisation of the field crew

The field team comprised 3 people, the researcher, an assistant, and a local forest official. The researcher was responsible for identifying the location of transects, and for recording measurements made in the plots and in-between plots. The assistant's job was to navigate from plot to plot, to demarcate the boundary of the plot and to identify and call out plant species names and counts for recording which were also verified by the researcher. A local forest official accompanied the team, as usually the inventory of a government-controlled forest can not be undertaken without involving local forest department in the exercise.

3.5. Indicators of forest 'naturalness'

Forests of the Salt range belong to a single forest type and comprise a small number of plant species distributed fairly evenly through out the area. Because of their simple composition, classification of these forests is not difficult. To achieve the purpose of this study, the forests of the area were classified into two categories i.e. semi-natural and degraded forests. FAO (1997) defines 'semi-natural' forests as those, which have been modified by humans through use and management. In this document, naturalness is characterised by such elements as a complex spatial structure, a composition and distribution of native species, a wide range of ages in tree species and the presence of dead and decaying trees. This report states that there is no specific definition of the term 'naturalness' which has led to the use of often loosely-defined terms such as 'virgin forests', 'primary forests', 'old growth forests'', 'natural forests' and 'semi-natural forests'.

In this study, the following indicator vegetation characteristics of semi-natural forests have been selected from available local literature:

1. Tree height

Olea ferruginea and *Acacia modesta* are the two dominant tree species of the area. Both are highly palatable and heavily exploited for fodder, fuelwood, and small timber (Sheikh, 1987; Champion, Seth and Khattak, 1965). Champion, Seth and Khattak (1965) and Said (1956) reported that in degraded forests both these tree species were either absent or survived in a stunted bush form. This finding suggests that these species are expected to be taller in height in semi-natural forests.

2. Tree canopy cover

Under the most favourable conditions, which include protection from human disturbance, the forests form a more or less closed canopy (Sheikh, 1987; Champion, Seth and Khattak, 1965). Hence, it can be safely assumed that the tree canopy cover would be higher in semi-natural forests as compared to degraded forests.

3. Presence of climax species

As mentioned earlier, both the climax tree species and an associated shrub species (*Dodonaea viscosa*) are over-exploited for fuelwood, fodder, and small timber (Champion, Seth and Khattak, 1965; Sheikh, 1987; Hussain, 1999). The climax species face the threat of complete elimination. Therefore, it is expected that these species are still present in the remaining semi-natural forests but absent from most of the degraded forests.

In the light of the above mentioned indicator characteristics of semi-natural forests, the following criteria were used to classify the semi-natural forests of the study area:

1. Mean plot tree height > 6m.
2. Plot tree canopy cover > 50 %, and
3. At least 3 out of 4 climax plant species, including both the tree species i.e. *Olea ferruginea* and *Acacia modesta* were present in the plot.

Sample plots were classified in the field as belonging to semi-natural forest class if the vegetation in the plot matched with the criteria, otherwise, it was classified as degraded forest. Under these criteria of classification, it is possible that some areas that are natural grass-dominated meadows or natural open woodlands or pure natural forest i.e. primarily single tree species forests, may be erroneously labelled as degraded forests.

In remote sensing, among other factors, the spectral reflectance of vegetation depends on the density of canopy cover, the type of plant species (e.g. conifer or deciduous) and the growth phase (e.g. mature or young) of the vegetation. The selected criteria have another advantage, that it takes into account all these aspects of vegetation's spectral reflectance characteristics. Therefore, it is assumed that these criteria would also be useful in image processing and classification.

3.6. Image classification

The geo-referenced and atmospherically corrected satellite image obtained from WWF-Pakistan was classified during the post-fieldwork phase. Using expert knowledge, a boundary map of the study area was digitised from a coarse-scale (1:250 000) topographic map. This map was then used to pull out the study area from the satellite image.

3.6.1. Knowledge-based image analysis

Knowledge-based image classification uses expert knowledge to classify the image (Richards, 1993). From our knowledge of vegetation's spectral characteristics, we know that vegetation reflectance is more in the near-infra red bands than in the visual part of the electromagnetic spectrum.

In the case of NDVI, the theoretical range of values is between –1 to +1. Actually measured values range from –0.35 (water) through zero (soil) to +0.6 (dense green vegetation. Vegetation cover can be compared between different soil types at NDVI values of 0.05 or higher (Groten, Immerzeel and Leeuwen, 1999). This corresponds to a DN value of 135 or higher after scaling the NDVI image to the image domain (0-255). Thus it can be assumed that all pixels with NDVI less than 135 are either water bodies, or bare soil, or settlements or with very little green cover. To eliminate the above land cover types from the scene, the following rule was applied to the remotely sensed data.

If NDVI < 135 or NDVI > 195 **then** eliminate (mask) the pixel, **otherwise** no change.

Visual inspection of some irrigated agriculture areas on the image that were located in the south of the study area, revealed some NDVI values that were higher than 195. Therefore, it was assumed that such very high values relate to intensively irrigated agriculture. In order to remove such areas from the scene an upper NDVI limit of 195 was entered in the above rule.

Even after the application of the above rule, there remained some areas on the image, which belonged to either less intensive agriculture or orchard land use types. Such areas were identified on the image from expert knowledge (reconnaissance survey) and FCC (false colour composite) and subsequently removed by on-screen delineation followed by using map calculation function in ILWIS. Finally, upon the removal of all unwanted land cover types (water, bare soil, orchards, settlements and agriculture), only natural vegetation cover type was supposedly left on the image. To make sure that no roadside plantations or small home gardens were left on the scene, a 5 x 5 majority filter in ILWIS was applied to the image after running a supervised classification. The application of majority filter removes isolated and very small groups of connected pixels of a land cover class.

3.6.2. Supervised classification

The supervised classification method was used to classify the natural vegetation land cover class into two classes i.e. semi-natural and degraded forest. Supervised classification is the procedure most often used for quantitative analysis of remote sensing image data. It rests upon using suitable algorithm e.g. minimum distance and maximum likelihood, to label the pixels in an image as representing particular land cover classes.
Main steps involved in this procedure are:

1. Decide the set of land cover classes which were just two in this study i.e. semi-natural and degraded forest.
2. Select pixels for training data from ground truth. Richards (1993) recommends the selection of 30-60 pixels for each land cover class collected from different sections of the image.
3. Use the training data to estimate the parameters of the particular classifier algorithm to be used.
4. Using the trained classifier, label every pixel in the image into one of the land cover classes, and
5. Produce maps or tables (Richards, 1993).

The maximum likelihood classifier is the most common supervised classification method used with remote sensing image data. It uses both the mean and covariance information for each spectral class. On the other hand, Box and Minimum distance to the mean classifiers do not take into account the spread of data. Consequently, maximum likelihood classifier gives better results in general (Richards, 1993). In this study, maximum likelihood classifier with a threshold distance of 100m (default in ILWIS) was used.

3.6.3. Classification accuracy of remote sensing data

The most common way to represent the classification accuracy of remotely sensed data is in the form of an error or confusion matrix (Congalton, 1991). In this matrix, the columns represent the reference data (ground truth or test pixels) while the rows indicate the classification generated from the remotely sensed data. As an example, a confusion matrix for two hypothetical land cover classes is given in table 3-5. Computations involved in accuracy measurements are also presented below the table.

Table 3-5: An example of a Confusion matrix

MAP CLASSES	REFERENCE DATA (# of test pixels)	ROW TOTAL

	A	B	
A	110	9	119
B	19	53	72
COLUMN TOTAL	129	62	191

Overall accuracy = (110+53)/191 x 100 = 85.3 %

Producer's accuracy:

A = 110/129 x 100 = 85.2 %

B = 53/62 x 100 = 85.5 %

User's accuracy:

A = 110/119 x 100 = 92.4 %

B = 53/72 x 100 = 73.6 %

The simplest descriptive statistics is called 'overall accuracy', which is computed by dividing the total correctly labelled pixels i.e. the sum of the major diagonal, by the total number of pixels in the error matrix. The result is expressed in percentage. Besides overall accuracy, there are two other types of accuracies namely, 'producer's accuracy' and 'user's accuracy'. Producer's accuracy refers to the probability that a sampled point on the classified map is a particular land cover class. Producer's accuracy is calculated by dividing the correctly labelled pixels of a class by the column total while in the case of user's accuracy, row totals are used. User's accuracy is indicative of the probability that a pixel classified on the image actually belongs to that class on the ground. Richards (1993) favours the adoption of this measure of classification accuracy.

The simplest strategy for evaluating classifier performance is to randomly choose a set of test samples (pixels) for each land cover class and another set of training samples (pixels) that is used for running the classification (Richards, 1993). The selected samples can be a single pixel or a group of similar surrounding pixels (ITC, 1999). In this study, half of the field samples collected for each land cover class were randomly assigned to each set. The recommended sampling strategies in the context of land cover data are simple random sampling or stratified sampling (ITC, 1999). Training samples set was used in running the maximum likelihood classifier. Test samples set was used to compute the accuracy of the classification.

3.7. Conservation priorities

Several criteria are used to judge the conservation value of a forest. Evaluation schemes generally attempt to combine criteria in some way either subjectively or via a numerical index. The most widely used scientific criteria are diversity or richness of species/habitats, rarity, naturalness, size and representation (Margules, Nicholls and Pressey, 1988). The underlying objective in all schemes is the maintenance of biodiversity.

Peck (1998) writes that natural communities are ecologically valuable for conservation at landscape level. Among other values, these high quality examples provide a standard against which we can compare other sites, and should better support biodiversity. The author goes on to emphasise the importance of considering the overall pattern of vegetation, the ranges of patch size and shape and their position in relation to one another.

Laurance et al., (1997) give a simple ranking system to assess the relative value of existing forest remnants for biological conservation in the case of tropical forests. They assign high conservation values to fragments that are least disturbed, > 300 ha in size, roughly circular in shape, pre-dominantly forest, less isolated from other patches and less represented in protected areas. Fragment size has been the focus of the majority of studies that were undertaken to assess the fragmentation factors that may affect biodiversity (Zuidema, Sayer and Dijkman, 1996). Turner and Corlett (1996) make a strong case for increased persistence of plant species in fragments as small as 100 ha. However, birds and mammals may require significantly larger habitat areas (Corlett and Turner, 1997). As far as the efficient management of forests is concerned, the average forest compartment size in the study area is also about 100 ha (Said, 1956).

In his Principles of Reserve Design, Diamond (1975) rates larger forest patches of compact shapes (e.g. round) to be higher in conservation value than smaller and more irregularly shaped patches. Circular shapes have lower edge-area ratio and retain more interior area for sensitive species and communities. Edges are the contact zone between a patch and its surrounding environment. Edge zones are commonly dominated by plants and animals typical of disturbed sites (Norton, 1999).

Based on the above mentioned documents and the forest characteristics of the study area, the following criteria has been adopted for identifying priority areas for conservation:

1. Semi-natural forest type, which is presumably less disturbed also. Smith (1997) has emphasised the usefulness of locating protected areas in less disturbed zones.
2. Fragment size greater than 100 ha.
3. Patch shape, preferably compact (e.g. round or square). Patch shape index was calculated from the formula:
   $\textit{Shape index} = (\textit{perimeter})^2/\textit{area}$ (modified from Elkie, Rempel and Carr, 1999)
   For a circular patch of any size, shape index is 12.57, while it is 16 for a square shaped patch. Irregularly shaped patches have higher shape index.

In this study, the distance between patches or patch isolation was not considered of high importance since it was assumed that a patch of 100 ha or greater was large enough (Turner and Corlett, 1996) to maintain the plant species populations irrespective of its isolation or closeness to other patches. Moreover, effects of isolation are studied less frequently, since it is more difficult to quantify (Zuidema, Sayer and Dijkman, 1996).

It is worthwhile to mention here that the above patch sizes recommended by different authors do not specifically relate to the type of forests found in the study area. For such forests, optimum patch size for biodiversity conservation could be smaller or bigger than the one adopted here.

3.8. Spatial and remote sensing accuracy issues

Following are the major concerns of this study related to spatial accuracy issues:

1. Due to the non-availability of a topographic map of the study area, the satellite imagery could not be geo-referenced before fieldwork. During the fieldwork phase, a GPS was used to record positions of sample plots. These readings were recorded in the WGS-84 datum. After the fieldwork was over, a geo-referenced and atmospherically corrected copy of the same imagery was luckily obtained from WWF-Pakistan. This imagery was in Lambert Conformal Conic (LCC) projection, which is commonly used by the Survey department of Pakistan. According to WWF-Pakistan office the accuracy of this imagery was within acceptable limits i.e. RMSE (root mean square error) was less than one pixel or 30 meters. The GPS readings could be another source of error in determining the true position on ground. However, this error is generally less than 10-20 meters ever since the USA government decided to stop the selective availability option with effect from 1st of May, 2000 (www.geod.emr.ca/new/html-public/GSDinfo/English/gsd_sa.htm). GPS plus RMSE errors could result in assigning sample plots on the ground to wrong corresponding pixels on the image which in turn could affect the accuracy of image classification.

2. Forest boundaries of the government controlled forests and protected areas, and major roads in the study area were digitised from a 1:250 000 scale topographic map of the area prepared by the Survey of Pakistan. Sigma value for the digitised segment maps was 0.5 mm which means that the digitised segments were on average 125 meters off the true position on ground.

3. Every effort was made to remove cultivated farmlands and orchards from the image using expert knowledge, knowledge-based rules and visual interpretation of false colour composite and aggregate NDVI maps. However, there is no guarantee that all of the unwanted areas were removed. There is always a possibility that any of these remaining areas could be wrongly classified as a semi-natural forest during image processing.

3.9. Materials

The following is the list of key materials used in this study.

1. Landsat7 (ETM+) satellite imagery of the study area taken on 14th of July, 1999.
2. Global Positioning System (GPS). Garmin 12 XL.
3. Compass, clinometer, altimeter, and an ordinary tape.
4. 1:250 000 scale topographic map of the area showing boundaries of government controlled forests. This map was prepared by the Survey of Pakistan.

3.10. Flowchart of research methods

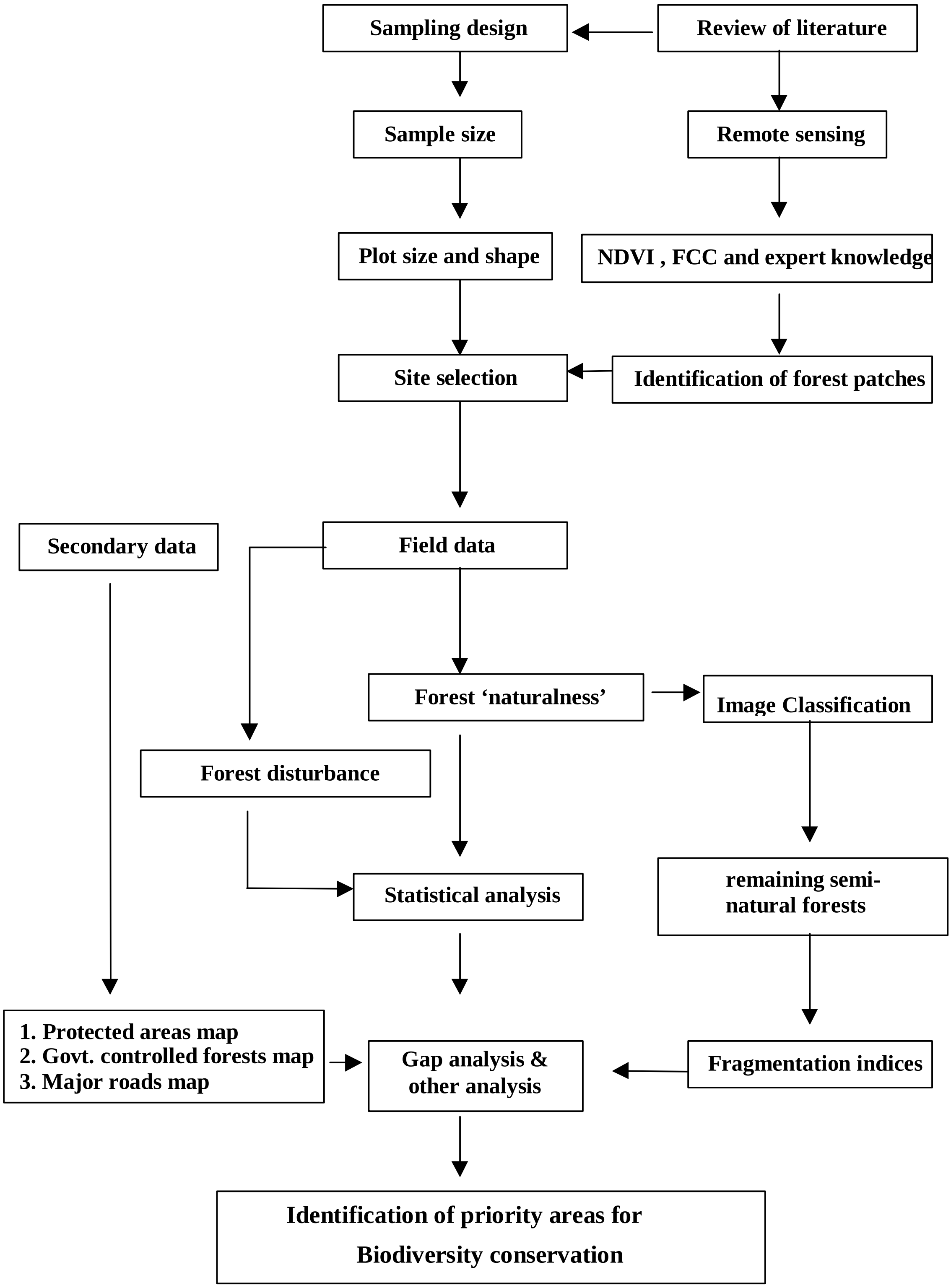


Figure 3-4: Flowchart of research methods

4. RESULTS

4.1. Vegetation characteristics of Eastern and Western forests

The eastern part of the study area receives more rainfall than the western part due to which its natural vegetation is somewhat more luxuriant. This difference was also noticed during the reconnaissance survey of the area carried out prior to fieldwork. However, silviculturally, the forests of the entire area are assigned to a single forest type i.e. dry sub-tropical broad-leaved forest since vegetation composition is largely homogenous through out. A single set of criteria was therefore, chosen for the entire study area to differentiate semi-natural forests from degraded forests without making any distinction between the eastern and the western parts. This set of criteria is described in chapter 3.

Before proceeding with data analysis, it was considered important to first check the similarity or otherwise of the vegetation characteristics of the two sites i.e. west and east. The purpose behind this analysis was to alter the criteria in case significant differences were found between the vegetation characteristics of the two areas. Vegetation characteristics that were used in this analysis are:

- Mean plot tree height (8m i.e.>6m class or 4.5m i.e. 3-6m class, only two classes)
- Plot tree canopy cover (>50% or <50%)
- Presence of climax plant species (presence signifies that at least three climax species including both the tree species were present in the plot)

Chi-square analysis was performed in MINITAB 12.22 (1998) to test the possible association between site and the above mentioned vegetation characteristics one by one. The results of this analysis are given in tables 4-1, 4-2, and 4-3.

Table 4-1: Site differences, according to mean plot tree height

MEAN PLOT TREE HEIGHT (meters)	**SITE**		ROW TOTAL (# plots)
	WEST	**EAST**	
8 m	17 (24.4)	29 (21.6)	46
4.5 m	27 (19.6)	10 (17.4)	37
COL. TOTAL (# plots)	44	39	83

Numbers indicate the number of plots in the particular height class

Chi-square = 10.7, DF = 1, P-value = 0.001

Values in parenthesis denote expected counts

Results of table 4-1 indicate an association between the two variables at 0.05 significance level and in this case even at lower level. As the observed count (29) for eastern forests in 8m-height category is greater than the expected count (21.6), we can say that there is a positive association between eastern forests and taller tree heights.

Table 4-2: Site differences, according to plot tree canopy cover

PLOT TREE COVER (%)	**SITE**		ROW TOTAL (# plots)
	WEST	**EAST**	
> 50 %	3 (14.8)	25 (13.2)	28
< 50 %	41 (29.2)	14 (25.8)	55
COL. TOTAL (# plots)	44	39	83

Numbers indicate the number of plots in the particular tree cover class
Chi-square = 30.3, DF = 1, P-value < 0.001
Values in parenthesis denote expected counts

Table 4-2 gives the results of the Chi-square analysis for site differences, according to plot tree canopy cover. According to the result, both the variables are associated at 0.05 significance level. Moreover, higher plot tree cover percentage (>50%) is positively associated with eastern forests since the observed count (25) is far more than the expected count (13.2).

Table 4-3: Site differences, according to presence of climax plant species in plot

CLIMAX SPP.	**SITE**		ROW TOTAL (# plots)
	WEST	**EAST**	
PRESENT	33 (35)	33 (31)	66
ABSENT	11 (9)	6 (8)	17
COL. TOTAL (# plots)	44	39	83

Numbers indicate the number of plots where the spp. were present or absent
Chi-square = 1.17, DF = 1, P-value = 0.28
Values in parenthesis denote expected counts

Results of table 4-3 indicate a lack of association between site and presence of climax plant species in the plots at 0.05 significance level. Both the variables tend to happen independent of each other.

From the results of tables 4-1 and 4-2 it is confirmed that forests of the eastern part are in general taller in height and denser as opposed to the drier western forests. Figure 4-1 presents these results in a graphical form. The diagram shows very clear differences in tree height and tree canopy cover between the two sites.

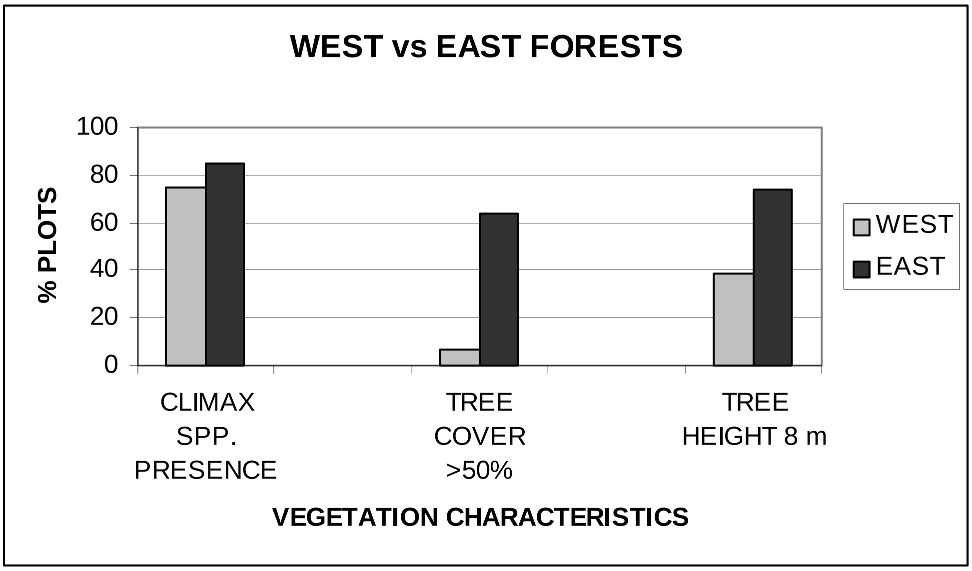


Figure 4-1: Differences in vegetation characteristics of eastern and western forests

The observed differences in vegetation characteristics of the two sites could either be due to natural factors alone e.g. a rainfall gradient or a result of multiple factors affecting the vegetation such as rainfall gradient coupled with disturbance gradients.

In the light of these findings, it was concluded that a single set of criteria for classifying the semi-natural forests was not equally applicable in both parts of the study area. Consequently, the criteria were adjusted to suit the western forests by lowering the minimum mean plot tree height and tree canopy cover standards to the next lower classes. The new set of criteria for classifying the semi-natural forests of the eastern and western sites are as under:

EAST (unchanged)	**WEST (altered)**
Minimum plot mean tree height > 6 meters	**minimum plot mean tree height > 3 meters**
Minimum tree canopy cover > 50 %	**minimum tree canopy cover > 25 %**
Minimum # of climax plant species present = 3	**minimum # of climax plant species present = 3**

Based on the above set of criteria, the distribution of semi-natural and degraded forest plots in both the sites is given in table 4-4. Subsequent data analysis was done separately for each site. In some cases, the two sites were compared. On the satellite image the study area was partitioned into eastern and western parts by arbitrarily choosing a major highway (Islamabad-Lahore motorway) that passes approximately through the middle of the area as the dividing line. Subsequent image processing was done separately for each part.

Table 4-4: Distribution of semi-natural and degraded forest plots in the study area

SITE	FOREST CLASS		ROW TOTAL
	SEMI-NATURAL (# of plots)	DEGRADED (# of plots)	
EAST	22	17	39
WEST	14	30	44
COL. TOTAL	36	47	83

A total of 83 sample plots were measured in the field, out of which 39 and 44, approximately proportional to the area under forest in these two areas, were situated in the eastern and western parts, respectively. As regards distribution of plots according to forest class, 36 plots were classified as belonging to semi-natural forest type while 47 plots were placed under degraded forest category.

4.2. Vegetation characteristics of gully and non-gully habitats

During fieldwork sample plots were taken in gully and non-gully transects. It was decided to check for the entire tract whether both should be regarded as belonging to a single population of forest type or to be treated differently, in case significant differences were observed in vegetation characteristics. Ideally, gully habitat should be analysed independent from non-gully habitat since gully habitat is unique and probably more favourable to vegetation due to better shade and soil moisture conditions.

But, as almost all the gullies in the area are dry through out the year (Said, 1956) therefore, in general, vegetation characteristics of gully site were not expected to be significantly different from non-gully site. In order to test the possible association between habitat (gully or non-gully) and vegetation characteristics (mean plot tree height, plot tree canopy cover, and presence of climax plant species), a Chi-square analysis was performed. The results of this analysis are given in tables 4-5, 4-6, and 4-7.

Table 4-5: Habitat differences, according to mean plot tree height

MEAN PLOT TREE HEIGHT	HABITAT		ROW TOTAL (# plots)
	GULLY	NON-GULLY	
8 m	19 (22.7)	27 (23.3)	46
4.5 m	22 (18.3)	15 (18.7)	37
COL. TOTAL (# plots)	41	42	83

Number indicate the number of plots in the particular height class

Chi-square = 2.71, DF = 1, P-value = 0.100

Values in parenthesis denote expected counts

Table 4-6: Habitat differences, according to plot tree canopy cover

PLOT TREE COVER (%)	HABITAT		ROW TOTAL (# plots)
	GULLY	NON-GULLY	
> 50 %	11 (13.8)	17 (14.2)	28
< 50 %	30 (27.2)	25 (27.8)	55
COL. TOTAL (# plots)	41	42	83

Numbers indicate the number of plots in the particular tree cover class
Chi-square = 1.72, DF = 1, P-value = 0.189
Values in parenthesis denote expected counts

Table 4-7: Habitat differences, according to presence of climax plant species in plot

CLIMAX SPP.	HABITAT		ROW TOTAL (# plots)
	GULLY	NON-GULLY	
PRESENT	30 (32.6)	36 (33.4)	66
ABSENT	11 (8.4)	6 (8.6)	17
COL. TOTAL (# plots)	41	42	83

Numbers indicate the number of plots where the spp. were present or absent
Chi-square = 2.004, DF = 1, P-value = 0.157
Values in parenthesis denote expected counts

Chi-square results given in tables 4-5, 4-6, and 4-7 indicate no association between habitat type and any of the three vegetation characteristics at 0.05 significance level. Hence, it is concluded that gully and non-gully vegetation characteristics are similar which also suggests that environmental conditions are fairly similar in both habitats. A comparison of vegetation characteristics of the two habitat types is presented in Fig. 4-2.

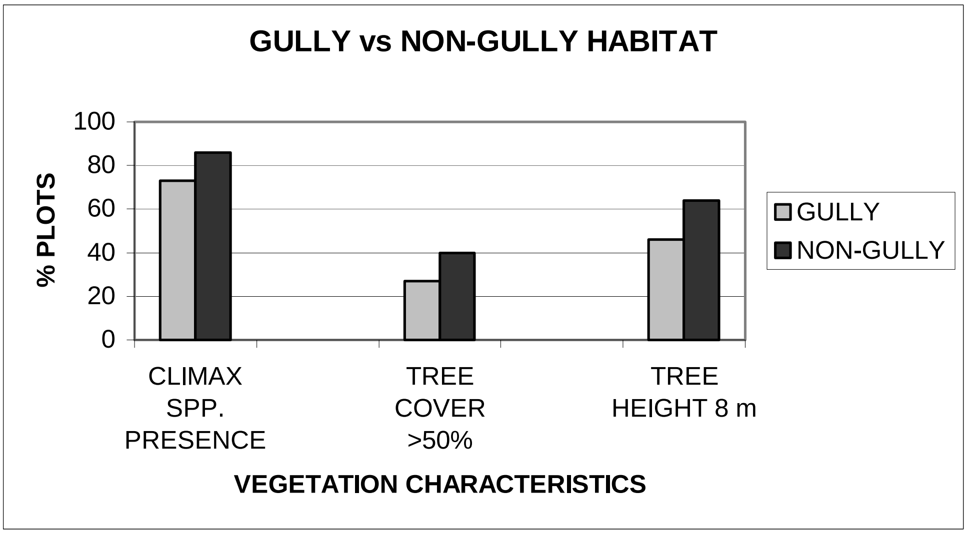


Figure 4-2: Differences in vegetation characteristics of gully and non-gully habitats

In fig. 4-2, non-gully vegetation appears to be in a slightly better shape. This could be due to higher disturbance that takes place in gully areas as they are relatively more accessible. Disturbance data (please refer to chapter 3 and section 4.3 for more details) for gully and non-gully plots suggests that gully areas are more disturbed than non-gully sites. The results of this comparison are given in table 4-8 and this could be the reason for the slightly poor condition of gully vegetation.

Table 4-8: Degree of disturbance in gully and non-gully habitats

DISTURBANCE INDICATOR	HABITAT	
	GULLY (% PLOTS)	NON-GULLY (% PLOTS)
HIGH GRAZING PRESSURE	59	24
HIGH SOIL EROSION	34	0
LOW WOOD DEBRIS	71	60
INVADER SPP. PRESENT	71	67

In the light of the above findings, no distinction was made in this study between gully and non-gully plots and both were combined together for data analysis. Finally table 4-9 gives the distribution of gully and non-gully plots measured in both the sites.

Table 4-9: Distribution of gully and non-gully plots in the study area

SITE	HABITAT		ROW TOTAL
	GULLY (# OF PLOTS)	NON-GULLY (# OF PLOTS)	
WEST	26	18	44
EAST	15	24	39
COL. TOTAL	41	42	83

Table 4-9 shows that 41 and 42 plots were measured in gully and non-gully habitats, respectively.

4.3. Forest Disturbance

Forests of the study area have been subjected to high pressures of human related disturbance since long, which has caused immense losses to local biodiversity. In this study, simple descriptive statistics has been used to ascertain that:

- which site is relatively more disturbed (east or west)
- which forest class i.e. semi-natural or degraded is relatively more disturbed. Here it was hypothesised that semi-natural forests are less disturbed relative to degraded forests.

The following indicators of forest disturbance, described in chapter 3, were measured to assess the degree of forest disturbance in the area:

- Grazing
- Soil erosion
- Occurrence of invasive species
- Wood debris on forest floor
- Signs of fire
- Signs of fresh lopping or stumps

As none of the sample plots indicated signs of forest fire or of fresh lopping or stumps, these indicators were not included in the subsequent analysis.

4.3.1. Forest disturbance according to site

A comparison of forest disturbance in the two sites is shown in Fig. 4-3.

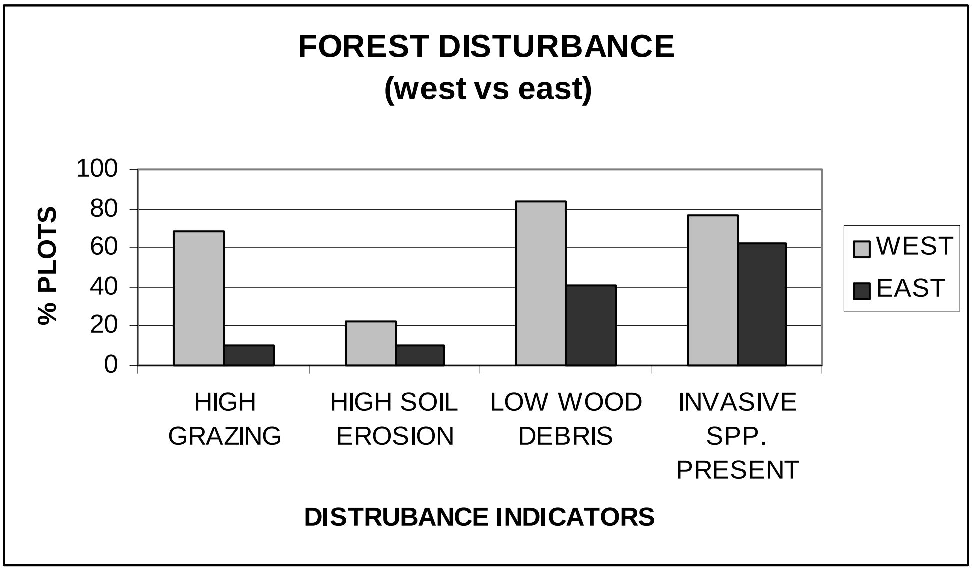


Figure 4-3: Comparison of forest disturbance in east and west parts

From figure 4-3, it is obvious that the western forests have a higher degree of soil erosion, higher grazing pressure, lower amounts of wood debris, and a higher presence of invasive plants species as compared to eastern forests. One reason for the higher degree of disturbance observed in western forests could be attributed to the fact that there were 26 gully plots measured in the western part as against 15 in the east. As also mentioned in section 4.2, gully habitats are found to be more disturbed than non-gully habitats. A second reason could be the semi-arid nature of western forests (low density and low biomass) which makes it difficult to qualify precisely the degree of disturbance. It is also possible that in reality the western forests are actually more disturbed than eastern forests.

4.3.2. Forest disturbance according to forest classes

The results of this comparison for each site are presented in Fig. 4-4 and Fig. 4-5.

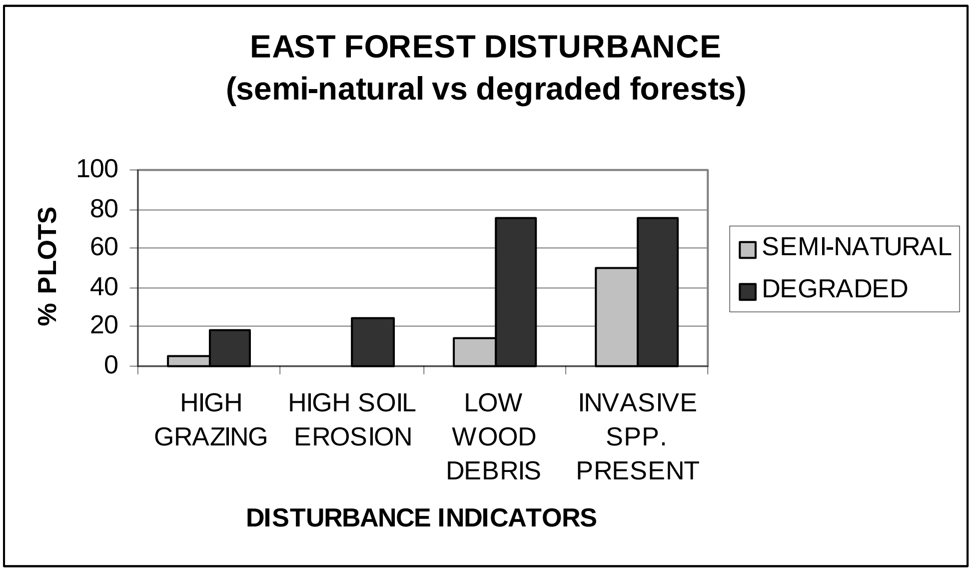


Figure 4-4: Semi-natural vs degraded forest disturbance in the eastern part

As shown in Fig. 4-4, in the case of eastern site, semi-natural forests are far less disturbed than the degraded forests. This proves the earlier hypothesis that semi-natural forests are less disturbed as compared to degraded forests. On the other hand, if we look at Fig. 4-5, which is the corresponding diagram for the western site, it is seen that the differences between disturbance in the two forest classes are not as marked as they are in the case of eastern forests.

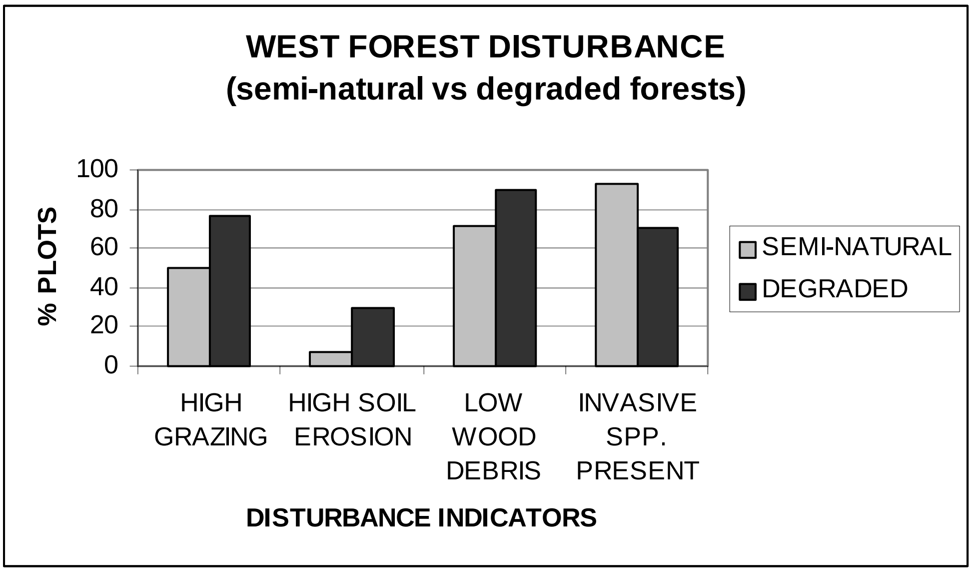


Figure 4-5: Semi-natural vs degraded forest disturbance in the western part

Again, the reason for observing a relatively low difference in the degree of disturbance of semi-natural and degraded forests of the western part could be the semi-arid nature of the vegetation which makes it difficult to qualify precisely the degree of forest disturbance by subjective methods.

4.4. Natural regeneration

Lack of natural regeneration of *Olea ferruginea* and *Acacia modesta* tree species is a major forestry problem of the area. According to Said (1956) and Champion, Seth and Khattak (1965) natural regeneration of these two tree species was almost absent in the entire tract. During fieldwork, data on the presence in plots of natural regeneration (<0.5m) of both the above mentioned climax tree species was collected. Descriptive statistical analysis was carried out to compare presence of natural regeneration in:

- Western vs Eastern forests
- Semi-natural vs degraded forests. The underlying hypothesis here is that natural regeneration is present in semi-natural forests but largely absent from degraded forests.

Table 4-10 gives the results of presence in plots of natural regeneration of both the species in western and eastern parts.

Table 4-10: Presence of natural regeneration in both sites

SITE	PRESENCE OF REGENERATION	
	OLEA FERRUGINEA (% PLOTS)	ACACIA MODESTA (% PLOTS)
WEST	5	34
EAST	15	44

Results of table 4-10 indicate a low difference between the sites. Natural regeneration of *Olea ferruginea* is very low compared to that of *Acacia modesta* which is also inadequate as it is present in even less than 50% of the plots in both sites.

A comparison of natural regeneration of the two tree species in semi-natural and degraded forests is given in table 4-11. The table shows a slightly higher presence of regeneration of both the species in semi-natural forests as opposed to degraded forests. Therefore, the earlier hypothesis which states that natural regeneration is present in semi-natural forests but absent from degraded forests, may not be true.

Table 4-11: Presence of natural regeneration in forest classes

FOREST CLASS	PRESENCE OF REGENERATION	
	OLEA FERRUGINEA (% PLOTS)	ACACIA MODESTA (% PLOTS)
SEMI-NATURAL	14	47
DEGRADED	6	32

In conclusion, lack of natural regeneration of both the tree species, particularly *Olea ferruginea* is indeed a matter for great concern. It is probably due to high grazing pressure since both the species are highly palatable and/or because of the type of silviculture system (coppice with standards) under which the forests of the area were managed to date.

4.5. Climax species

In general, climax plant species are associated with less disturbed or natural forests. It was therefore, hypothesised that these species are present in semi-natural forests but largely absent from degraded forests (please refer to 3.5). To check this, descriptive statistical analysis was performed for the climax tree species (*Acacia modesta* and *Olea ferruginea*) only.

Table 4-12: Presence of Climax tree species in forest classes

SITE	ACACIA MODESTA		OLEA FERRUGINEA	
	SEMI-NATURAL (% PLOTS)	DEGRADED (% PLOTS)	SEMI-NATURAL (% PLOTS)	DEGRADED (% PLOTS)
WEST	100	100	100	63
EAST	100	100	100	65

As shown in table 4-12, in the case of semi-natural forests, both the species were present in 100% of the plots since the criteria for semi-natural forest class was such. However, *Acacia modesta* was also present in 100% of the degraded forest plots both in the east as well as in the west. As for *Olea ferruginea*, it was present in 63% and 65% of the degraded forest plots in west and east respectively.

The above result attempts to answer research question # 1. These results suggest that climax species occurrence is not limited to semi-natural forests only. They are found in a high percentage of degraded forests as well. Therefore, the hypothesis may not be true. This result is understandable since both the species are fairly hardy and can bear with harsh environmental conditions (Champion, Seth and Khattak, 1965; Sheikh, 1987). This result further suggests that the selection of climax plant species as an indicator of semi-natural state of the forests may not be applicable to these forests.

4.6. Image classification

Image classification was carried out using Supervised and Knowledge-based classification methods. East and West parts were classified separately.

First of all, knowledge-based classification rules (explained in chapter 3) were used in order to remove all land cover types from the image except natural vegetation, which is the only land cover type of interest in this study. These unwanted land cover classes

were left out during supervised image classification. But later on, all these land cover types were given a single class name i.e. “others”.
Supervised image classification method (explained in chapter 3) was applied to classify the image into two forest classes i.e. semi-natural and degraded. In the first step of the supervised method, three bands (TM3, TM4, and NDVI) were selected to run the classification. The main reasons for selecting these three bands were that firstly, in remote sensing NDVI is widely applied in studying vegetation characteristics. Lee and Nakane (1997) used it to classify forest vegetation. Secondly, in this study, as described in chapter 3, an NDVI image was used to identify the candidate forest areas for data collection during fieldwork and it gave very good results in the field. Almost all the areas identified as forests were found to be actually forests on the ground. And thirdly, NDVI also compensates changes in illumination conditions, surface slopes and aspect.

Table 4-13 gives the details of the number of training and test samples used in running the maximum likelihood classifier for the two sites.

Table 4-13: Number of training and test samples, 3-band classification

SITE	TRAINING SAMPLES (# pixels)		TEST SAMPLES (# pixels)	
	Semi-natural forest	Degraded forest	Semi-natural Forest	Degraded forest
EAST	99	58	129	62
WEST	72	103	47	107

The accuracy of the classified maps was measured through confusion matrices. Tables 4-14 and 4-15 show the confusion matrices for east and west parts, respectively. Information about accuracy measurements is given under each table.

Table 4-14: Confusion matrix for classified eastern forests (3-band classification)

MAP CLASSES (FOREST)	REFERENCE DATA (# of test pixels)		ROW TOTAL
	SEMI-NATURAL	DEGRADED	
SEMI-NATURAL	110	9	119
DEGRADED FOREST	19	53	72
COLUMN TOTAL	129	62	191

Overall accuracy = (110+53)/191 x 100 = 85.3 %

Producer’s accuracy:
Semi-natural forest = 110/129 x 100 = 85.2 %
Degraded forest = 53/62 x 100 = 85.5 %

User’s accuracy:
Semi-natural forest = 110/119 x 100 = 92.4 %

Degraded forest = 53/72 x 100 = 73.6 %

Table 4-15: Confusion matrix for classified western forests (3-band classification)

MAP CLASSES (FOREST)	**REFERENCE DATA (# of test pixels)**		ROW TOTAL
	SEMI-NATURAL	DEGRADED	
SEMI-NATURAL	46	63	109
DEGRADED	1	44	45
COLUMN TOTAL	47	107	154

Overall accuracy = (46+44)/154 x 100 = 58.4%
Producer's accuracy:
Semi-natural forest = 46/47 x 100 = 97.8 %
Degraded forest = 44/107 x 100 = 41.1 %
User's accuracy:
Semi-natural forest = 46/109 x 100 = 42.2 %
Degraded forest = 44/45 x 100 = 97.8 %

The results of accuracy assessment indicate a fairly high overall accuracy for the eastern part (85.3%) but a low (58.4%) overall accuracy for the western part. Low accuracy for the western part could be due to the semi-arid nature (low density, low green biomass and more bare soil background) of the western forests. The results of accuracy assessment also depend upon the sampling design used to select test pixels, the number of test pixels selected and number of pixels in each sample unit (ITC, 1999).

In the next step, all the six optical bands (TM1, TM2, TM3, TM4, TM5 and TM7) were used in running the second classification with the aim to get better results since more spectral information was being used.

Table 4-16 provides details of the number of training and test samples used in this case. Confusion matrices are given in tables 4-17 and 4-18 along with accuracy measurements under each table. The results for overall accuracy have now improved slightly for the western part (61.2%) and are still fairly high (82.2%) for the eastern part. Therefore, in this study results of 6-band classification have been adopted.

Table 4-16: Number of training and test samples, 6-band classification

SITE	**TRAINING SAMPLES (# pixels)**		**TEST SAMPLES (# pixels)**	
	Semi-natural forest	Degraded forest	Semi-natural forest	Degraded forest
EAST	105	76	107	62
WEST	72	78	63	120

Table 4-17: Confusion matrix for classified eastern forests (6-band classification)

MAP CLASSES (FOREST)	**REFERENCE DATA (# of test pixels)**		ROW TOTAL
	SEMI-NATURAL	DEGRADED	
SEMI-NATURAL	91	14	105
DEGRADED	16	48	64
COLUMN TOTAL	107	62	169

Overall accuracy = (91+48)/169 x 100 = 82.2 %

Producer's accuracy:
Semi-natural forest = 91/107 x 100 = 85.0 %
Degraded forest = 48/62 x 100 = 77.4 %

User's accuracy:
Semi-natural forest = 91/105 x 100 = 86.7 %
Degraded forest = 48/64 x 100 = 75.0 %

Table 4-18: Confusion matrix for classified western forests (6-band classification)

MAP CLASSES (FOREST)	**REFERENCE DATA (# of test pixels)**		ROW TOTAL
	SEMI-NATURAL	DEGRADED	
SEMI-NATURAL	50	58	108
DEGRADED	13	62	75
COLUMN TOTAL	63	120	183

Overall accuracy = (50+62)/183 x 100 = 61.2 %

Producer's accuracy:
Semi-natural forest = 50/63 x 100 = 79.4 %
Degraded forest = 62/120 x 100 = 48.3 %

User's accuracy:
Semi-natural forest = 50/108 x 100 = 46.3 %
Degraded forest = 62/75 x 100 = 82.6 %

In addition to overall accuracy, user's accuracy is a useful measure for assessing the accuracy of the classification (Richards, 1993). It indicates the probability that a pixel classified on the image actually belongs to that class on the ground. User's accuracy for semi-natural forests of the western part is fairly low (46.3%) which means that roughly 50% of the area classified as semi-natural forest may not actually be a semi-natural forest on the ground. Or in other words, the classified map has over-estimated the extent of semi-natural forest area in the western part.

4.7. Spatial distribution of remaining semi-natural forests

The second research question of this study deals with the issue of spatial distribution of remaining semi-natural forests in the area. The answer to this question will provide us with the information as to the extent, distribution and location of the remaining semi-natural forests so that necessary conservation measures could be undertaken. Figure 4-6 shows the spatial distribution of the remaining semi-natural forests in the eastern and western parts of the study area (GIS procedures of this analysis are given in appendix 2). Boundaries of government controlled forest lands are also shown on the map.

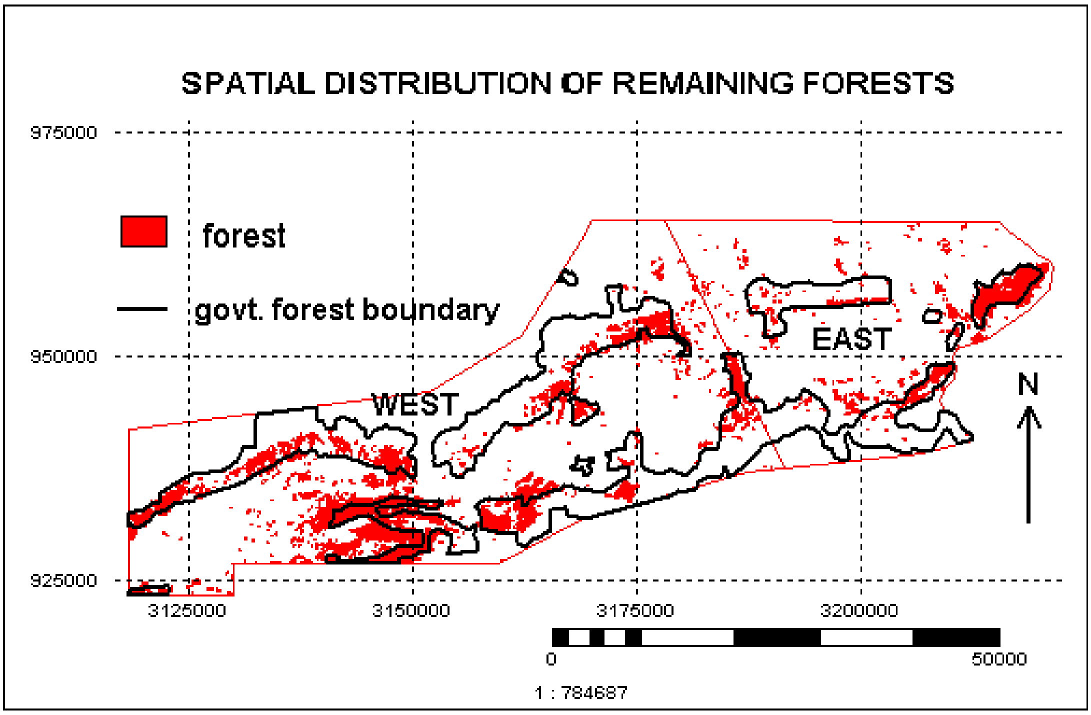


Figure 4-6: Map showing the spatial distribution of remaining semi-natural forests

Visual inspection of Figure 4-6 tells us that the remaining semi-natural forests are mostly located within government controlled forest areas. Regarding site, these forests are present in both parts, although within the sites, they are not uniformly distributed. In the case of eastern part, there is a large compact forest patch just below the upper right corner, while the northern and southern regions seem to be devoid of semi-natural forests. As for western forests, there is a large compact forest patch in the centre-south region.

Some statistics of the remaining semi-natural forests was also computed. Results reveal that there are 3 575 ha and 12 432 ha of semi-natural forests left in the eastern and western parts, respectively. About 68% of the eastern forests survive in government controlled lands while in the case of western forests this percentage is about 60%.

4.8. Forest fragmentation

Assessment of fragmentation is a good indicator of the status of forest biodiversity. Many fragmentation indices exist that indicate the degree of forest fragmentation. Such measures of forest fragmentation could provide us with useful information in deciding about what to conserve and where to conserve. By relating these indices to factors responsible for fragmentation e.g. agriculture activity or distance to road, we can also understand the cause and effect relationships. The analysis carried out under this section is an attempt to answer the third research question which is about the assessment of forest fragmentation.

4.8.1. Fragmentation Statistics

Using Patch Analyst 2.0 software (Elkie, Rempel and Carr, 1999) in ArcView vector theme, some fragmentation statistics of the semi-natural and degraded forests were calculated (GIS procedures are explained in appendix 4). The details of these statistics are given in tables 4-19 and 4-20 for semi-natural and degraded forests, respectively.

Table 4-19: Fragmentation statistics of semi-natural forests

SITE	ENTIRE LANDSCAPE			GOVT. FORESTS			PRIVATE FORESTS		
	CA	MPS	NP	CA	MPS	NP	CA	MPS	NP
EAST	3 575	7.3	491	2 439	14.2	172	1 136	3.2	358
WEST	12 436	9.7	1 281	7 445	11.7	633	4 987	6.3	794

CA = Forest class area in hectares

MPS = Mean patch size in hectares

NP= Number of patches

Table 4-20: Fragmentation statistics of degraded forests

SITE	ENTIRE LANDSCAPE			GOVT. FORESTS			PRIVATE FORESTS		
	CA	MPS	NP	CA	MPS	NP	CA	MPS	NP
EAST	30 774	27.4	1 123	5 916	20.4	290	24 152	25.8	935
WEST	23 283	9.6	2 418	8 499	7.8	1 088	14 749	9.2	1 607

CA = Forest class area in hectares

MPS = Mean patch size in hectares

NP= Number of patches

In tables 4-19 and 4-20, NP of the entire landscape should be equal to the sum of NPs of the government and private forests. However, the tables show a difference. Just as an example, in table 4-20, if we add 935 (NP of private forests in east) and 290 (NP of government forests in east), the sum is 1 225 whereas the table shows the figure 1 123.

This discrepancy is probably because vector theme was used in the analysis rather than raster (grid) theme. Interestingly, CA (class area) figures do not give such error.

Results of fragmentation statistics given in table 4-19 reveal that in both the eastern and western parts, mean patch size of semi-natural government controlled forests is greater than the mean patch size for the private forests. Likewise, number of patches in relation to area is less in the case of government forests as compared to private forests. These results indicate that semi-natural government forests are less fragmented than semi-natural private forests probably due to better protection measures in government forests.

Regarding degraded forests, table 4-20 indicates that degraded government forests have a smaller mean patch size as compared to private forests. This result suggests that the process of degradation is probably expanding more rapidly in private forests than government forests.

As per the above tables, the total government controlled forestland in the eastern part is calculated as 8 355 ha, of which 29% is in semi-natural state and the rest (71%) in degraded state. Compared to this, the total government controlled forestland in the west is 15 944 ha, of which 47% is in semi-natural state while remaining (53%) is degraded.

Here, it is worth mentioning that the classified map has over-estimated the semi-natural forest area of the western part by as much as 100%. For details, please refer to 4.6. Applying this correction would leave about 25-30% semi-natural government controlled forest area in both parts.

According to the above tables, the total private forest area in the eastern part is 25 288 ha, of which merely 4% is semi-natural. On the other hand, there are 19 736 ha of private forests in the western part of which 25 % (uncorrected) are in semi-natural state. The results suggest that government controlled forestlands have a higher percentage of semi-natural cover than privately held forests. In this analysis all forests lying outside government controlled forestlands were assumed to be private forests.

An important point to be mentioned here is that all spatial statistics was computed after applying 5 x 5 majority filter to the classified image in order to simply it as it contained a large number of small polygons with large variation in classes for neighbouring pixels. In general, the majority filter reduces the amount of class areas. As an example, the semi-natural forest area calculated for the eastern part from the classified image was 5 342 ha, which reduced to 3 575 ha after filtering. Likewise, filtering reduced the semi-natural forest area of the western part from 13 745 ha to 12 432 ha. However, filtering has an advantage too i.e. it removes from the image very small isolated patches of man-made (i.e. not natural) forests such as roadside trees and home gardens.

4.8.2. Relationship between fragmentation & anthropogenic & environmental factors

Forest fragmentation occurs when it sub-divided by a natural disturbance e.g. fire or by human activities e.g. roads or agriculture (Dale and Pearson, 1997). In this study, it was decided to examine whether there exists a relationship between forest fragmentation and distance to major roads and between forest fragmentation and environmental factors such as aspect, slope, and elevation. In order to examine the relationship with environmental factors, a DEM (digital elevation model) is needed, which was however not available for the study area. This part of the analysis was, therefore, dropped.

a) Relationship between distances to road and number of small (<5 ha) semi-natural forest patches

The GIS procedures described in appendix-5 were used to study this relationship. Following major roads of the study area were included in this analysis.

EAST	WEST
1. Kallar Kahar to P. D. Khan via C. Saidan Shah	1. Kallar Kahar to Khushab
2. Bhaun to Kallar Kahar	2. Pail to Ucchali via Khabbeki
3. Chakwal to Choa Saidan Shah	

Distances to roads were selected from practical experience, and ranged from 0 to 10 km on either side of the road with a class interval of 1 km. According to table 4-19 the mean patch size of semi-natural forests is about 8.5 ha. If the issue is to divide the patch size distribution into 3 categorical classes i.e. small, medium and large, and assuming that the patch sizes are normally distributed then patches up to 5 ha would be roughly classified as small patches. A highly fragmented forest is expected to have a higher number of small patches than a less fragmented forest (Smith, 1997).

Table 4-21 gives the number of small semi-natural patches in each distance to road class for the eastern and western parts. In the case of western part, number of small patches reaches a maximum (170) at 3-km distance to the nearest road while it reaches the maximum (78) at a distance of 2-km to the nearest road in the east. It is also seen that as the distance to road increases, the number of patches declines. The trends are more or less similar in both parts. Figure 4-7 presents these findings in graphical form.

Table 4-21: Number of small (<5ha) forest patches in each distance to road class

SITE	DISTANCE TO ROAD (km)										
	0-0.5	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.5	9.5-10.5
EAST	65	75	78	72	50	53	43	21	6	3	2
WEST	65	151	138	170	147	130	135	100	58	18	9

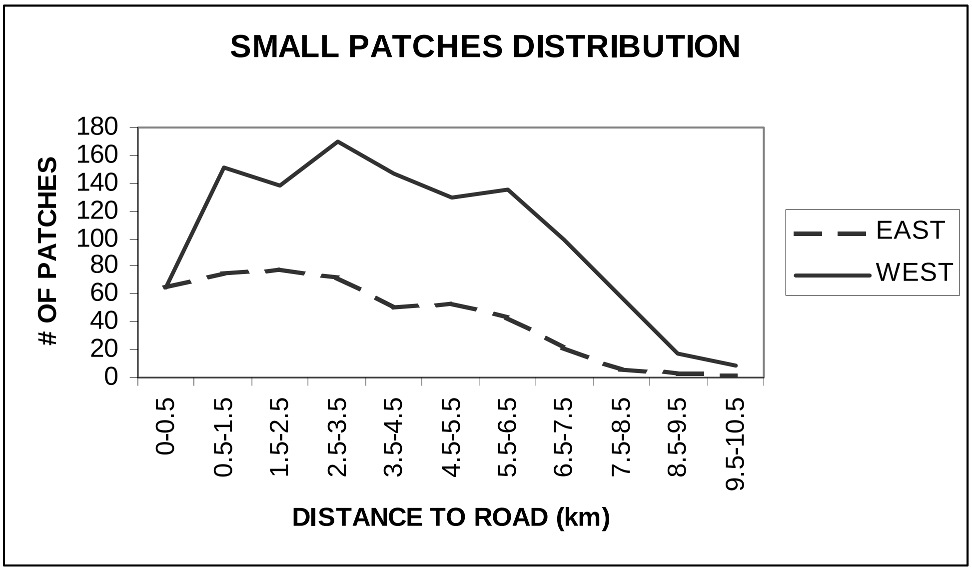


Figure 4-7: Distribution of small patches

The results indicate that in general fragmentation of semi-natural forests is highest at around 2-3 km distances to road, beyond which it declines as distance increases. These results match with the ground situation. Most of the development in the area takes place near roads. Nearly all the major settlements are situated along these roads. These areas are either devoid of forests or have few small forest patches. Cultivated areas and grazing lands surround these settlements. Forests, that are situated closer to such developed sites are therefore, more likely to be highly disturbed and hence more fragmented than the forests of less disturbed (further away from road) sites. In this analysis, it is possible that forest patches that are located at the boundary of a distance to road class may be counted in both the neighbouring classes.

b) **Relationship between distances to road and forest class area**

GIS procedures of this analysis are given in appendix 5.

Table 4-22 presents this data. Forest class areas in percentage were calculated by dividing the individual forest class area in each distance to road class by the total area of the distance to road class. Figures 4-8 and 4-9 describe the relationships in diagrams for eastern and western parts respectively.

Table 4-22: Forest class areas in % according to distances to road classes

DISTANCE TO ROAD (km)	EAST FORESTS (% area)		WEST FORESTS (% area)	
	SEMI-NATURAL	DEGRADED	SEMI-NATURAL	DEGRADED
0-0.5	1	33	3	16
0.5-1.5	4	38	9	19
1.5-2.5	4	44	11	24
2.5-3.5	5	46	12	26
3.5-4.5	4	49	11	22
4.5-5.5	5	45	12	19
5.5-6.5	7	33	12	19
6.5-7.5	6	23	12	12
7.5-8.5	8	20	6	6
8.5-9.5	6	17	1	2
9.5-10.5	5	13	1	1

As per results, semi-natural forest area % increases gradually with increase in distance to roads reaching a maximum at a distance of 8 km and 6 km respectively for east and west parts.

On the other hand, degraded forests tend to have highest area % closer to roads which is at 4-km and 3-km distances respectively for east and west parts. These results are more or less similar for both the sites.

Here again the results agree with the ground situation confirming that degraded forests are generally located closer to roads (high disturbance area) while semi-natural forests are found further away from roads in relatively less disturbed zones. At distances beyond 8-9 km from the roads, the percentage area of semi-natural and degraded forests drops considerably. It is due to the reason that we have reached the outer boundary of the study area where there are few forests.

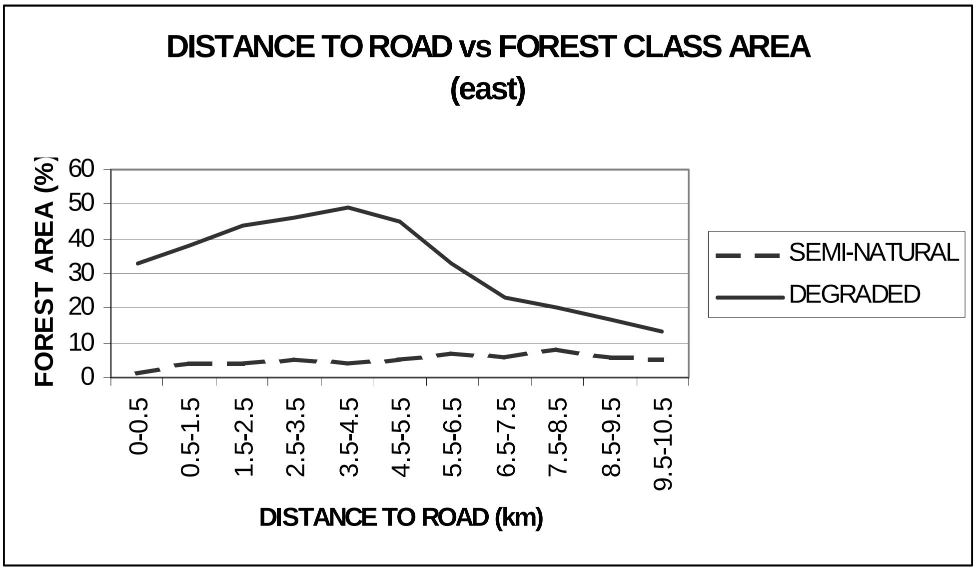


Figure 4-8: Relationship between distances to road and forest class area (%) for east

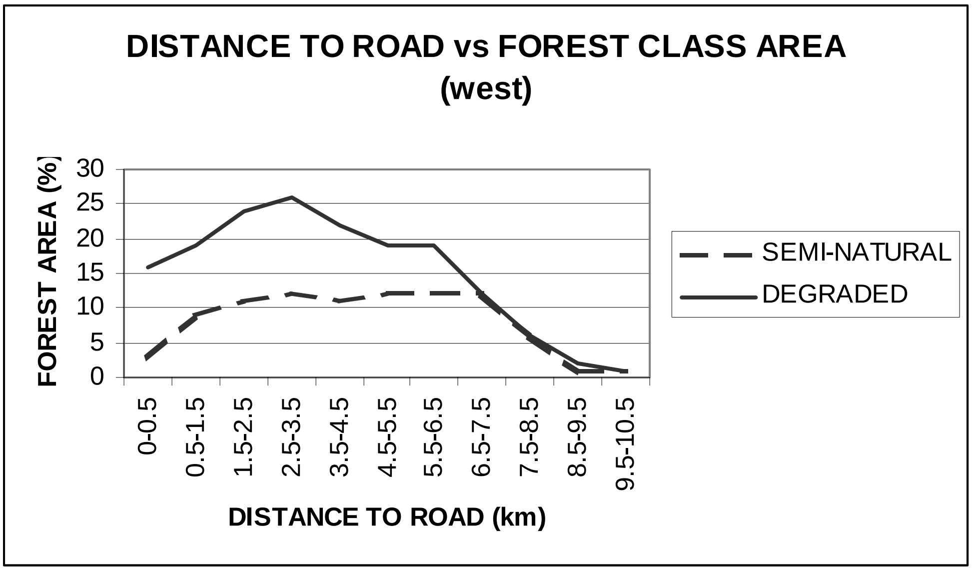


Figure 4-9: Relationship between distances to road and forest class area (%) for west

In the light of the above results it is concluded that roads are a major factor in forest fragmentation in the area. This finding has two important implications for conservation planning, which are:

- Stricter protection measures are required for protected areas that are situated closer to roads since they are probably more vulnerable to disturbance.
- No development should be allowed near the recently built motorway that passes through the area, otherwise it would have negative effects on surrounding forests.

4.9. Priority semi-natural forest patches for conservation

Identification of priority semi-natural forest patches for conservation is the ultimate objective of this study. This section attempts to answer research question number 4 which deals with the evaluation of conservation value of remaining patches (please refer to 3.7). Appendix-3 describes the GIS procedures used in this exercise.

The classified maps for the eastern and western parts contained a large number of widely scattered semi-natural forest patches. There were 491 such patches in the east and 1281 in the west with mean patch size of 7.3 hectares and 9.7 hectares respectively (table 4-19) which are quite small sizes from conservation viewpoint (Laurance et al., 1997). They consider a minimum patch size of 300 ha as of high value for biodiversity conservation in the case of tropical forests. But they also stress that it should not be considered as a hard and fast rule since even small forest patches may have important biological values.

As explained in chapter 3, in this study a minimum patch size of 100 ha was chosen as the standard for the conservation of biodiversity and efficient management. According to this standard, 4 semi-natural patches were identified in the eastern part and 13 in the western part. Details of these patches are given in tables 4-23 and 4-24.

As shown in the tables, shape index for each patch was also computed (methods described in chapter 3). Besides patch size, patch shape is an important factor in the assessment of the conservation value of a patch. Regular shapes such as a circle or square have less shape index value compared to irregularly shapes. Shape index for a circle is 12.57 while it is 16 for a square. Conservationists recommend the selection of regular shaped patches since they have less edge to area ratios and are therefore, less prone to external influences and probably more promising for biodiversity conservation. However, in this study the purpose of calculating shape index is mainly to highlight the degree of threat to a patch from external disturbances. Patches that have a relatively high shape index perhaps require more conservation efforts. There is a large patch in the western part that has a very high shape index (1 213.8). Similarly, patches that are closer to roads (<5 km distance, please refer to 4.8.2) have been marked to indicate that those patches may need additional protection measures as they, probably, lie in disturbed zone. A map showing the identified priority forest patches for conservation is given in figure 4-10.

Table 4-23: ***Details of priority forest patches of the eastern part***

PATCH ID	AREA (ha)	SHAPE INDEX	LOCATION COORDINATES (patch centre approx.)	
			X	Y
1	792	104.3	3 218 190	958 613
2*	1 181	185.7	3 214 322	956 463
3*-	263	173.7	3 208 381	948 136
4*	105	67.5	3 205 990	945 464

* denotes centre of patch is < 5 km horizontal distance from nearest road approximately
- includes a 30 ha government owned orchard, exact location not known
Coordinates: Projection-Lambert Conformal Conic, Spheroid-Everest, Datum-Indian (Bangladesh)

Table 4-24: ***Details of priority forest patches of the western part***

PATCH ID	AREA (ha)	SHAPE INDEX	LOCATION COORDINATES (patch centre approx.)	
			X	Y
1	259	153.2	3 176 705	954 486
2*	195	105.0	3 177 671	953 219
3	237	137.4	3 175 317	952 555
4	198	131.1	3 186 603	946 883
5	284	132.6	3 166 264	946 641
6*	160	187.5	3 168 739	944 649
7	254	149.6	3 173 627	934 993
8*	761	247.2	3 162 462	933 424
9*	523	66.4	3 158 721	931 553
10*	512	254.0	3 147 756	938 248
11*	105	96.8	3 148 921	936 840
12*+	4 490	1 213.8	3 146 358	930 747
13	346	249.3	3 122 771	933 861

* denotes centre of patch is < 5 km horizontal distance from nearest road approximately
+ denotes shape index is probably very high
Coordinates: Projection-Lambert Conformal Conic, Spheroid-Everest, Datum-Indian (Bangladesh)

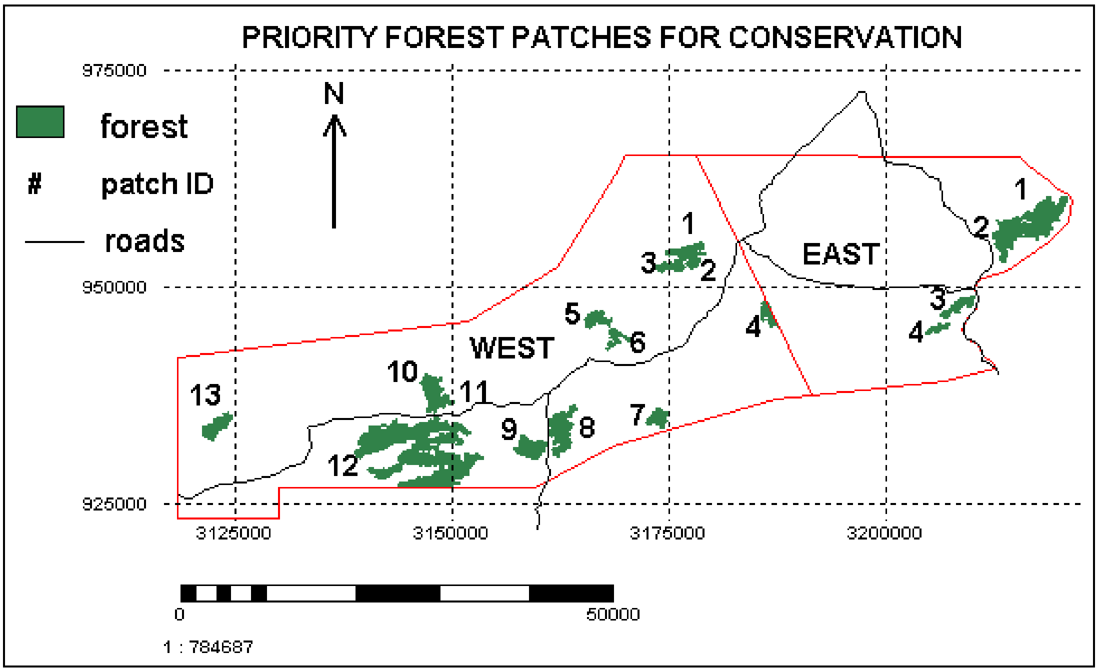


Figure 4-10: Map showing identified priority forest patches for conservation

4.10. Gaps in biodiversity conservation

As mentioned in chapter 1, there are three protected areas within the study area. Chinji National Park (6 095 ha) and Sodhi Wildlife sanctuary (5 820 ha) are situated in the western part while Chumbi-Surla Wildlife sanctuary (55 945 ha) is located in the eastern part.

Unfortunately a map of Sodhi Wildlife sanctuary could not be obtained despite efforts. Boundary maps of the other two protected areas were prepared by digitising. The map of Chumbi-Surla Wildlife sanctuary gives an area of 29 977 ha while in literature (WCMC, 1991; Jan, 1993) the area is stated as 55 945 ha. However, the map is taken to be reliable since it was obtained from local Wildlife office.

To see the gaps in forest conservation and to answer research question number 5, the map showing priority forest areas for conservation was overlaid with protected area map and government forest boundaries map in ILWIS 2.1 (1997). Figure 4-11 illustrates the gaps in conservation.

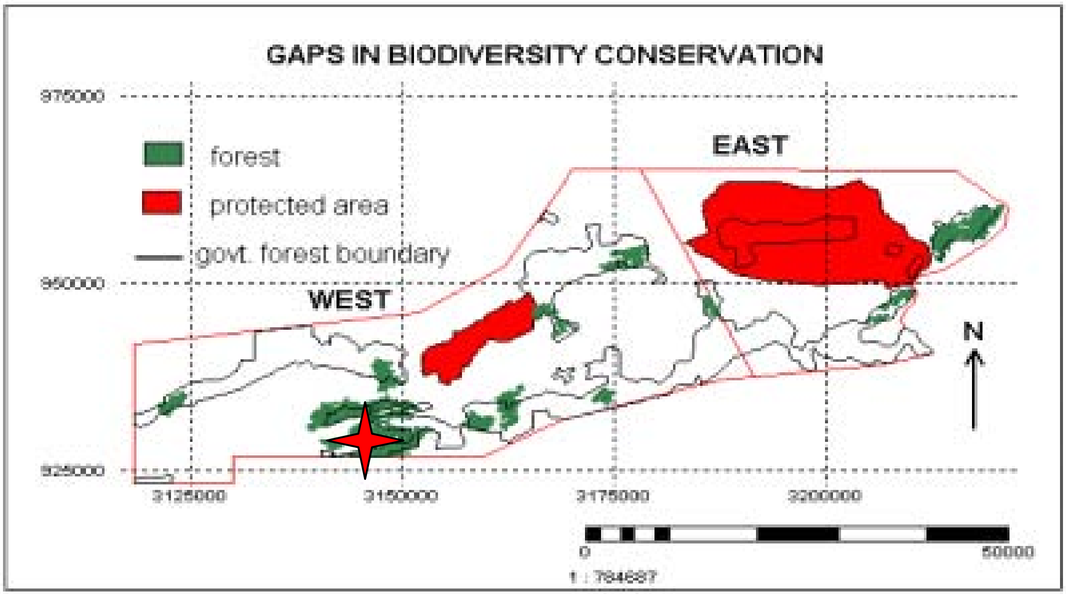


Figure 4-11: Map showing gaps in biodiversity conservation

Indicates a protected area (Sodhi Wildlife sanctuary) in this part, map not available.

In figure 4-11, it is evident that except for one large patch in the western part, none of the other forest patches is covered in the existing protected areas. There is a reason for this omission. The existing protected areas were established with the objective to protect a wild sheep (Urial-*Ovis vignei punjabiensis*) which does not necessarily require semi-natural forest habitat (Roberts, 1977). The map also shows that a large part of the identified patches falls within government controlled forests which are also protected areas but of a lower status.

4.11. Rare plant species

Any biodiversity conservation plan prepared for an area would be incomplete and ineffective unless it takes care of rare species. In this study, data was collected on the presence in plots of 3 rare plant species of the area namely *Pistacia integerrima* (tree), *Tecoma undulata* (tree), and *Monotheca buxifolia* (shrub). Whereas, *Pistacia integerrima* and *Tecoma undulata* were found in very few plots i.e. in just 8% and 6%m respectively, *Monotheca buxifolia* occurred in many plots (58%) which suggests that this shrub many not be a rare species at all.

In addition to plot data, GPS was used to record the approximate locations of both the rare tree species if they were detected on the way while moving from plot to plot in transects. From the ground locational data of both the species, separate GIS layers (point maps) were prepared. This information was used in knowing whether the forest areas that are identified as priority areas for conservation also contain some of these rare tree species. Figure 4-12 shows the results of this analysis wherein rare tree species point maps have been overlaid on the map showing priority forest patches for conservation. It is clear from figure 4-12 that both the rare tree species are present in some of the identified priority forest patches for conservation. This result implies that the conservation of priority areas would contribute to the conservation of rare tree species as well. It is further possible that these species might exist in some of the other patches as well, which were not visited during fieldwork.

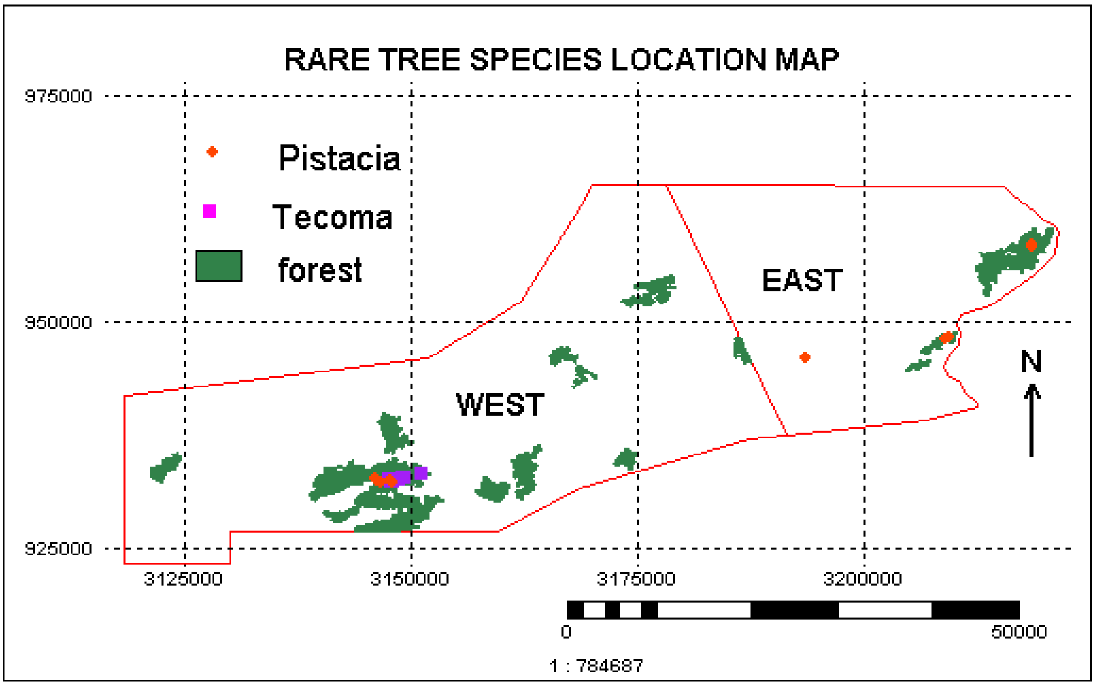


Figure 4-12: Distribution of rare tree species in relation to priority forest patches

4.12. Environmental data

During fieldwork, data on plot aspect, slope and elevation was recorded with the intention to use it later on for studying relationships with vegetation characteristics. However, this analysis was not performed due to the following reasons:

1. Slope % was recorded mainly with the purpose to determine plot radius.
2. Due to issues of accessibility and limited time, 85% of the plots were taken in the elevation range from 500 m to 800 m, whereas actually the forests of the study area are found from 450 m to 1200 m elevation range approximately. Therefore, as the collected data did not cover all the elevation range, it was not analysed.
3. Regarding aspect data, again due to accessibility, time and weather factors, about 46% of the plots had 'flat' aspect since most were taken in gullies with gentle slopes. Moreover, there were less than 5 plots each in Eastern, Western, North-eastern, North-western, and South-western aspects. Therefore, this data set was also considered in-sufficient for analysis.

5. DISCUSSIONS

5.1. Differences between Eastern and Western forests

Dissimilarity exists between the vegetation characteristics of the two sites. Forests of the eastern part are in general taller in height and denser as opposed to the drier western forests. The observed differences in vegetation characteristics of the two sites could either be due to natural factors alone e.g. a rainfall gradient or a result of multiple factors acting together such as disturbance plus a rainfall gradient. As far as the presence of climax plant species is concerned both sites show little difference which is probably due to the resilient character of climax plant species of the area that can survive in harsh environmental conditions. This means that mere presence or absence of a plant species in an area is not a good indicator of its health. These results also make us realise the need to deal with the forests of the two sites on their own merits. Treating the forests of the entire Salt range as a homogeneous entity may not be the correct approach. Significant variations exist between the western and the eastern parts.

5.2. Differences between vegetation of gully and non-gully habitats

A broad similarity was observed between the vegetation characteristics of gully and non-gully habitats, which suggests that environmental conditions are fairly similar in both habitats. Gully sites are expected to have deeper soils and better soil moisture conditions. But owing to the semi-arid nature of the area, most gullies are dry through out the year and severely eroded as well. According to the results non-gully vegetation, surprisingly, appears to be in a slightly better shape. This could be due to the higher disturbance that takes place in gully areas as they are relatively more accessible. Regarding plant species diversity, it may be mentioned here that gully habitats could be richer in plant species diversity as in some gully transects few plant species e.g. naturally occurring *Dalbergia sissoo* (a very important timber species that is mostly grown artificially) and a wild almond species were observed.

5.3. Forest disturbance

As mentioned in 5.2, gully areas were found to be more disturbed than non-gully areas due to their higher accessibility and perhaps the presence of relatively more grass cover. Western forests seemed to have a higher degree of soil erosion, higher grazing pressure, lower amounts of wood debris, and a higher presence of invasive plants species as compared to eastern forests. However, it was difficult to measure precisely the disturbance level of the drier western forests by employing subjective methods. Such forests have low density and low biomass and thus they apparently give the impression of higher disturbance.

Overall, semi-natural forests were found to be relatively less disturbed than degraded forests, which is quite understandable. This is also confirmed from the fragmentation statistics of semi-natural and degraded forests, which revealed that degraded forests were, situated closer to roads (more developed and populated areas) while semi-natural forest patches were further away.

5.4. Natural regeneration

In the entire Salt range, natural regeneration of *Olea ferruginea* is very low while that of *Acacia modesta* is also inadequate. A slightly higher presence of regeneration of both the species was found in semi-natural forests as opposed to degraded forests. Lack of natural regeneration of these two main tree species is either due to heavy grazing pressure or an effect of the silviculture system under which the forests of the area have been managed to date. Further research is needed to ascertain the cause(s) of this problem and to mitigate the situation.

5.5. Climax species

The results suggest that climax species occurrence is not limited to semi-natural forests only. They are found in a high percentage of degraded forests as well. This is understandable since both *Acacia modesta* and *Olea ferruginea* are tolerant species and can bear with harsh environmental conditions (Champion, Seth and Khattak, 1965; Sheikh, 1987). This result further suggests that the selection of climax plant species as an indicator of semi-natural state of the forests may not be applicable to these forests.

5.6. Image classification

NDVI gave very good results in identifying forest areas for subsequent investigation and data collection during fieldwork. Similarly, during the image classification phase, NDVI transformation gave results that are comparable to all-bands classification. Although, it was not tested statistically, but there seems to be no significant difference between the results obtained from NDVI classification and those obtained from all six-band classification.

Classification accuracy was quite low for the drier western forests therefore the classification results may not be very reliable. This was mainly due to semi-arid vegetation characteristics of the area i.e. low tree canopy cover, low biomass and more soil background making it difficult for the remote sensing sensor to differentiate between bare soil and vegetation. For such type of vegetation, SAVI (soil-adjusted vegetation index) may give better results (Huete, 1989). Moreover, the 30m spatial resolution of the ETM+ data may not be suitable for classifying shrub and grass vegetation (May, Pinder and Kroh, 1997; Marceau, Howarth and Gratten, 1994). They recommend the use of SPOT data, which has a spatial resolution of 20m. The use of ancillary data on elevation, slopes and soil types in combination with remote sensing data may help to resolve confusion among vegetation types with similar spectra and thus improve classification accuracy (Skidmore, 1989).

5.7. Forest fragmentation

The results of forest fragmentation indicate that semi-natural government forests are relatively less fragmented than semi-natural private forests perhaps due to better protection measures in government forests. The results further suggest that government controlled forests have a higher percentage of remaining semi-natural forest cover than privately held forests. These results are true to the ground situation. However, it does not imply that government forests are in an excellent condition. Fragmentation statistics for the government forests reveals their insecure status i.e. a quite small mean patch size, large number of patches and low percentage area under remnant semi-natural forests. The process of forest fragmentation is strongly linked with the existence of major roads of the area. These roads can be considered as a sign of area's development since all the major towns of the area are situated along these roads. These findings are comparable to Dale and Pearson (1997) who found that forests in highly developed zones were more fragmented than those in less developed areas.

5.8. Selection of priority areas for conservation

4 semi-natural forest patches were identified in the eastern part and 13 in the western part according to the criteria described in chapter 3. These criteria are mainly based on semi-natural forest patch size, which in this case was a minimum of 100 ha. Definitely, a reduction or increase in the minimum patch size criterion would lead to a corresponding increase or decrease in the total number of forest patches identified for conservation. Further research is needed to determine the optimum patch size for the effective conservation of plant species and the associated wildlife. Similarly, the effect of patch shapes on the local plant and animal species needs to be investigated. The selected criteria for identifying priority areas for conservation in this study are deficient in some respects. Some important wildlife habitats such as natural grass-dominated meadows or natural open woodlands, which are preferred by both partridges and Urial (Roberts, 1977 and 1991) do not fit into the definition of semi-natural forests (please see section 3.5) as used in this study. Therefore, the selection of any other suitable criteria for biodiversity conservation may give results different from the results of this study..

5.9. Gaps in biodiversity conservation

Except for one large patch in the western part, none of the other forest patches is covered in the existing protected areas. There is a reason for this omission. The existing protected areas were established with the objective to protect a wild sheep (Urial-*Ovis vignei punjabiensis*) which does not necessarily require semi-natural forest habitat (Roberts, 1977). A large part of the identified patches falls within government controlled forests which are also protected areas but of a lower status. Apparently, there are considerable gaps in biodiversity conservation. These findings match with those reported by Ramesh, Menon, and Bawa (1997) in India.

5.10. Rare plant species

Both the rare tree species were found in very few plots and in very few numbers. It could be due to the sampling design adopted in this study (Acharya, 1999) or it may also suggest that both the species indeed have narrow distribution and low populations. Although both are not endemic (Sheikh, 1993) but still they are worth protecting for their biological values. The rare shrub species (*Monotheca buxifolia)* occurred in many plots and its population size was also not low which suggests that this shrub many not be a rare species at all. This may be true, since in some documents e.g. WCMC (1991) and Champion, Seth and Khattak, (1965) it is not listed as a rare species.

Both the rare tree species are present in some of the identified priority forest patches for conservation. This result implies that the conservation of priority areas would contribute to the conservation of rare tree species as well.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

- Forests of the eastern and the western parts of the Salt range differ in vegetation characteristics such as tree height and tree canopy cover. However, plant species composition is more or less alike in both the parts.
- Climax plant species that are indicators of semi-natural forests, occur in degraded forests as well. Therefore, mere presence of these species should not be interpreted as an indicator of the state of the forest.
- NDVI is a good predictor of forest vegetation of the area, particularly, when remote-sensing data is collected during summer rainy season as found in this study. Results of image classification obtained by using NDVI are comparable to those obtained by using all TM spectral bands. However, for the drier western forests of the study area, classification accuracy is quite low. The use of any other vegetation index such as SAVI (soil-adjusted vegetation index) or ancillary data such as DEM (digital elevation model) in combination with remote sensing data may improve classification accuracy for the western forests. Moreover, remote-sensing data of a higher resolution such as SPOT may also give better results.
- The remaining semi-natural forests are located mainly within government controlled forest lands. However, private lands do have a considerable extent of these forests. Regarding site, these forests are present in both the western and the eastern parts, although within the sites, they are not uniformly distributed. Because of the low classification accuracy for the semi-natural western forests, the results of their spatial distribution and fragmentation statistics are not very reliable.
- Semi-natural government controlled forest lands are relatively less fragmented as compared to private forests. The process of degradation is probably expanding more rapidly in private forestlands than in government forests. Mean patch size of the remaining semi-natural forests of the area is quite small i.e. only 8.5 ha roughly, but there are two patches that are over 1 000 ha in size, one each in the eastern and the western parts. The large patch in the western part is probably an aggregate of a number of smaller patches but was wrongly identified as a single patch due to classification error i.e. low accuracy.
- The process of forest fragmentation is strongly linked with the existence of roads in the area. Semi-natural forests that lie closer to major roads are more fragmented than those that are located at a greater distance. Similarly, degraded forests occur near roads.
- There are a large number of semi-natural forest patches in the area. Smallest of these are less than one hectare in size while the largest are over 1 000 ha. Even

small patches may have important biological values. In addition to patch size, its shape, isolation and location with respect of disturbance gradients is worth considering. Unless detailed local research is conducted to ascertain the optimum patch attributes for effective biodiversity conservation, it is difficult to evaluate the conservation value of remaining patches. In this study, the optimum patch attributes for identifying priority areas for conservation have been selected from non-local research findings, which may or may not be effective in conserving the biodiversity of the Salt range.

- Semi-natural forests are understandably less disturbed than degraded forests, which justifies their protection.
- Considerable gaps exist in biodiversity conservation. Although, except for one, none of the other identified forest patches is covered in the existing network of the highest level of protected areas nonetheless a large part of these patches falls within government controlled forest lands which are also designated as protected areas but are of a lower status.
- A total of 17 priority forest patches for biodiversity conservation have been identified. Remote sensing and GIS are powerful and very useful tools for biodiversity assessment, mapping and conservation planning.
- Non-availability of a large scale and up-to-date topographic map critically limits the use of remote sensing data. Usually, availability of topographic maps is taken for granted and the concern is only about the availability of suitable remote sensing data. However, in this study, the case was opposite. For effective biodiversity conservation planning for a large area such as the Salt range, topographic information for image geo-referencing and construction of DEM is as crucial as is remote sensing data.
- Biodiversity maps are an important source of information for managers and planners involved in conservation planning. Such maps can be used to ensure that biologically rich sites are not left under or un-represented in the network of protected areas.

6.2. Recommendations

- Historical research combined with time series data, particularly satellite images taken over the last twenty years, are needed to monitor and model the process of forest fragmentation in the Salt range. Effective conservation for the Salt range requires that far more basic inventory data as well as more precise data on the status of plant and animal species and ecosystems be collected.
- Community and private forestry should be promoted in the area to conserve remaining privately owned forests and to reduce pressure on government forestlands. Better protection measures are also required in government forestlands. Involving and enlisting local communities' participation and co-operation in conservation matters can solve many biodiversity and peoples needs related problems.

- The forest patches identified in this study as priority areas for conservation should form the core zone in any proposed reserve design. In case it is not possible due to land management issues, then these areas, at least, deserve far greater attention and protection.
- It is recommended that forest management plans be prepared for both the government and the community forestlands and separately for the eastern and the western parts of the Salt range.
- It would be a good idea to test the usefulness of remote sensing for mapping the open woodland habitats of Urial species and partridges.
- Further research is recommended to assess the dependence of local people on the shrub forests of the Salt range in order to understand the process of forest fragmentation.

RERERENCES

Acharya, B. 1999. *Forest Biodiversity Assessment: A spatial analysis of tree species diversity in Nepal*. Publication No. 72, ITC, Enschede, the Netherlands.

Al, E. and L. Kuiper. (eds.). 2000. *Dutch Woodlands*. Stichting ProBos, Zeist, the Netherlands.

ArcView GIS. 1996. Using ArcView GIS. ESRI, Inc. USA.

Bannari, A., D. Morin, F. Bonn, and Huete, A.R. 1995. A review of vegetation indices. *Remote Sensing Reviews*. (13) 95-120.

Borota, J. 1991. *Tropical forests: some African and Asian case studies of composition and structure*. Elsevier, Amsterdam.

Champion, H.G., S.K. Seth and G.M. Khattak. 1965. *Forest Types of Pakistan*. Pakistan Forest Institute, Peshawar, Pakistan.

Congalton, R.G. 1991. A review of assessing the accuracy of classification of remotely sensed data. *Remote sensing of Environment*, 37:35-46.

Corlett, R.T. and Turner, I.M. 1997. Long-term survival in tropical forest remnants in Singapore and Hong Kong. In: *Tropical Forest Remnants: ecology, management and conservation of fragmented communities.* eds. W.F. Laurance and R.O. Bierregaard, Jr. University of Chicago Press, Chicago. 333-345 pp.

Dale, V.H. and S.M. Pearson.1997. Quantifying Habitat Fragmentation due to Land use change in Amazonia. In: *Tropical Forest Remnants: ecology, management and conservation of fragmented communities.* (eds.). W.F. Laurance., and R.O. Bierregaard, Jr. University of Chicago Press, Chicago. pp 400-409.

Dallmeier, F. 1998. Measuring and Monitoring forest Biodiversity: The SI/MAB model. In: *Assessment of Biodiversity for improved Forest Planning*. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. eds. P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp 15-29.

De Gier, A. 1992. Forest Mensuration (fundamentals), Lecture notes, Forest Science Division, ITC.

Diamond, J.M. 1975. The island dilemma: Lessons of modern biogeographic studies for the design of nature reserves. *Biological Conservation* 7:129-145.

Dudley, N. and J.-P. Jeanrenaud. 1998. Needs and prospects for international cooperation in assessing forest biodiversity: An overview from WWF. In: *Assessment of Biodiversity for improved Forest Planning*. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. eds. P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp 31-41.

Elkie, P., R.S. Rempel and A. Carr. 1999. Patch Analyst User's manual. Ontario Ministry of Natural Resources, Ontario, Canada.

ERDAS IMAGINE 8.4. 1999. Erdas, Inc. USA.

FAO. 1997. *State of World's forests*. Rome.

Forman, R.T.T. and M. Godron. 1986. *Landscape Ecology*. John Wiley and Sons, Inc.

Franklin, J.F., K. Cromack, W. Denison, et al. 1981. Ecological characteristics of old-growth Douglas-fir forests. USDA Forest Service General Technical Report PNW-118. Pacific North-west Forest and Range Experiment station, Portland, Oregon.

Fung, T. and K. Chan. 1994. Spatial composition of spectral classes: a structural approach for image analysis of heterogeneous land-use and land cover types. *Photogrammetric Engineering and Remote Sensing*. 60, 173-180.

GOP(a). 2000. Government of Pakistan. *District census report of Chakwal, 1998*. Census publication No. 77. Population census organization, Islamabad.

GOP(b). 2000. Government of Pakistan. *District census report of Khushab, 1998*. Census publication No. 64. Population census organization, Islamabad.

GOP. 1980. Government of the Punjab. Notification of ban on commercial fellings in the Salt range. Government of the Punjab, Lahore.

GOP. 1992. Government of Pakistan. *Forestry sector master plan (National perspective)*. Islamabad.

GOP-IUCN. 1992. *The Pakistan National Conservation Strategy*. IUCN, Karachi.

Groten, S.M.E., W. Immerzeel and L.van Leeuwen. 1999. *Monitoring of crops, rangelands and food security at national level*. ITC-FAO, Rome.

Hafeez, M. and M. Afzal. 1989. Assessment of dependence of local population on scrub forests in District, Jhelum. *Pakistan Journal of Forestry* 39:2, 71-77.

Harris, L.D. and K.R. Miller. 1984. *The fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity*. University of Chicago Press, Chicago.

Howard P.C., P. Viskanic and F.W. Kigenyi. 1998. Biodiversity assessment for conservation planning in Uganda's Forests. In: *Assessment of Biodiversity for improved Forest Planning*. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. (eds.). P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp.263-272.

Huete, A.R. 1989. Soil influences in remotely sensed vegetation-canopy spectra. In: *Theory and Applications of Optical Remote Sensing*. ed. G. Asrar. John Wiley and Sons, Inc. 107-141 pp.

Huete, A.R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment.* 25, 295-309.

Hussain, R.W. 1999. *Review of existing agroforestry systems in the Punjab*. Punjab Forestry Department (Pakistan) and Hunting Technical Services, UK.

ILWIS 2.1. 1997. User's guide. ITC, Enschede, The Netherlands.

Ingram, G.B. 1992. Landscape indicators for conservation of biological diversity: An example from Haida Gwaii, British Columbia. In: *Landscape Approaches to Wildlife and Ecosystem Management.* Symposium proceedings. (eds.). G.B. Ingram and M.R. Moss. Polyscience publications Inc. Morin Heights, Canada. 99-134 pp.

ITC. 1999. Principles of Remote Sensing. Textbook. ITC, Enschede, the Netherlands.

IUCN. 1980. *World Conservation Strategy: Living Resources Conservation for Sustainable Development*. Gland, Switzerland.

IUCN. 1990. IUCN Directory of South Asian Protected Areas. IUCN, Gland, Switzerland and Cambridge, UK. 294 pp.

Jan, U. 1993. *Review and analysis of forest policies of Pakistan*. Pictorial Printers (Pvt.) Ltd., Islamabad.

Kaewsonthi, S. and A.G. Harding. 1992. *Starting, managing and reporting research*. Chulalongkorn University Press, Bangkok.

Kapos, V. and S.F. Iremonger. 1998. Achieving Global and Regional Perspectives on Forest Biodiversity and Conservation. In: *Assessment of Biodiversity for improved Forest Planning*. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. (eds.). P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp 3-13.

Kent, M. and P. Coker. 1992. *Vegetation Description and Analysis: a practical approach*. Belhaven Press, London.

Laurance, W.F., R.O. Bierregaard, Jr., C. Gascon, R.K. Didham, A.P. Smith, A.J. Lynam, V.M. Viana, T.E. Lovejoy, K.E. Sieving, J.W. Sites, Jr., M. Anderson, M.D. Tocher, E.A. Kramer, C. Restrepo, and C. Moritz. 1997. Tropical Forest Fragmentation: synthesis of a diverse and dynamic discipline. In: *Tropical Forest Remnants: ecology, management and conservation of fragmented communities.* (eds.). W.F. Laurance and R.O. Bierregaard, Jr. University of Chicago Press, Chicago. pp. 502-514.

Lee, N.J. and K. Nakane. 1997. Forest vegetation classification and biomass estimation based on Landsat TM data in a mountainous region of west Japan. In: *The use of remote sensing in the modelling of forest productivity*. (eds.). H.L. Gholz, K. Nakane and H. Shimoda. Kluwer Academic Publishers, Amsterdam, the Netherlands. pp. 159-171.

Leprieur, C., Y.H. Kerr, S. Mastorchio and J.C. Meunier. 2000. Monitoring vegetation cover across semi-arid regions: comparison of remote observations from various scales. *International journal of remote sensing*. Vol-21(2), 281-300.

Lillesand, T.M. and R.W. Kiefer. 2000. *Remote sensing and image interpretation*. John Wiley and Sons, Inc.

Marceau, D.J., P.J. Howarth and D.J. Gratten. 1994. Remote sensing and the measurement of geographical entities in a forested environment. 1. The scale and spatial aggregation problem. *Remote Sensing of Environment* 49, 93-104.

Margules, C.R., A.O.Nicholls and R.L. Pressey. 1988. Selecting networks of reserves to maximise biological diversity. *Biological Conservation* 43:63-76.

Mather, P.M. 1999. *Computer processing of remotely-sensed images: an introduction.* John Wiley and Sons, Inc.

May, A.M.B., J.E. Pinder III. and G.C.Kroh. 1997. A comparison of Landsat Thematic Mapper and SPOT multi-spectral imagery for the classification of shrub and meadow vegetation in northern California, USA. *International journal of remote sensing* 18(18):3719-3728.

McCormick, N. and S. Folving. 1998. Monitoring European forest biodiversity at regional scales using satellite remote sensing. In: *Assessment of Biodiversity for improved Forest Planning*. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. (eds.). P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp 283-289.

McNeely, J.A., K.R. Miller, W.V. Reid, R.A. Mittermeier, and T.B. Werner. 1990. *Conserving the World's Biological Diversity*. IUCN, Gland, Switzerland.

MINITAB 12.22. 1998. Minitab, Inc. USA.

Norton, D.A. 1999. Forest Reserves. In: *Maintaining Biodiversity in Forest Ecosystems*. (ed.). M.L. Hunter, Jr. Cambridge University Press, Cambridge. 525-555 pp.

Noss, R.F. 1990. Indicators for monitoring Biodiversity: A Hierarchical Approach. *Conservation Biology* 4(4), 355-364.

Parker, T.A.P. III., A.H. Gentry, R.B. Foster, L.H. Emmons and J.V. Remsen, Jr. 1993. *The Lowland Dry Forests of Santa Cruz, Bolivia: A Global Conservation Priority*. Rapid Assessment Program Working Papers No. 4. Conservation International, Washington D.C., USA / Fundaci\n Amigos de la Naturaleza, La Paz, Bolivia. 104 pp.

Parviainen, J. and R. Päivenen. 1998. Information needs for Biodiversity assessment derived from International Forestry discussions. In: *Assessment of Biodiversity for improved Forest Planning*. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. (eds.). P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp. 63-70.

Peck, S. 1998. *Planning for Biodiversity: issues and examples*. Island Press, Washington D.C.

Peterken, G.F. 1996. *Natural Woodland: Ecology and Conservation in Northern Temperate Regions*. Cambridge University Press, Cambridge.
Ramesh, B.R., S. Menon and K.S. Bawa. 1997. A vegetation based approach to biodiversity gap analysis in the Agastyamalai Region, Western Ghats, India. *Ambio* 26(8), 529-536.

Reid, W.V., J.A. McNeely, D.B. Tunstall, D.A. Bryant and M. Winograd. 1993. *Biodiversity indicators for policy makers.* World Resources Institute, Washington DC, USA.

Richards, J.A. 1993. *Remote sensing digital image analysis: an introduction*. Springer-Verlag, Berlin.

Riney, T. 1982. *Study and management of large mammals*. John Wiley and Sons, Inc.

Roberts, T.J. 1977. *The Mammals of Pakistan*. Ernest Benn Limited, London.

Roberts, T.J. 1991. *The Birds of Pakistan*. vol-1. Oxford University Press, Karachi.

Said, R.M. 1956. *Working Plan for the forests of the Jhelum, Mianwali, and Shahpur Forest divisions from 1952-53 to 1981-82*. Vol-1. Government printing, Lahore.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchida, T.C. Edwards, Jr., J. Ullliman and R.G. Wright. 1993. Gap Analysis: A geographic approach to protection of Biodiversity. Wildlife Monograph. The Wildlife Society, USA.

Sheikh, M.I. 1987. *Forests and Forestry in Pakistan*. Pakistan Forest Institute, Peshawar, Pakistan.

Sheikh, M.I. 1993. *Trees of Pakistan*. Pictorial Printers (Pvt.) Ltd., Islamabad.

Skidmore, A.K. 1989. An expert system classifies eucalyptus forest types using Thematic Mapper data and a digital terrain model. *Photogrammetric Engineering and Remote Sensing*, 55, 1449-1464.

Smith, A.P. 1997. Deforestation, Fragmentation, and Reserve Design in western Madagascar. In: *Tropical Forest Remnants: ecology, management and conservation of fragmented communities.* (eds.). W.F. Laurance and R.O. Bierregaard, Jr. University of Chicago Press, Chicago. pp. 415-441.

Stoms, D.M. and J.E. Estes, 1993. A remote sensing research agenda for mapping and monitoring biodiversity. *International journal of remote sensing*. Vol-14, 10, 1839-1860.

The NEWS. 14-10-1997.

Turner, I.M. and R.T. Corlett. 1996. The conservation value of small, isolated fragments of lowland tropical rainforest. *Trends in Ecology and Evolution*. 11:330-333.

WCMC. 1992. World Conservation Monitoring Centre. *Global Biodiversity: Status of the Earth's Living Resources*. Chapman and Hall, London.

WCMC. 1996. The WWF World Forest Map. WCMC, Cambridge, UK.

WCMC. 1991. Biodiversity guide to Pakistan.

WRI. 1992. World Resources Report 1992-93. WRI, Washington D.C, USA.

WRI-IUCN-UNEP. 1992. *Global Biodiversity Strategy: Guidelines for Action to Save, Study, and Use Earth's Biotic Wealth Sustainably and Equitably.*

WWF-IUCN-GOP. 1995 ?. *Pakistan Biodiversity Action Plan*. IUCN, Karachi.

Zuidema, P.A., J.A. Sayer and W. Dijkman. 1996. Forest Fragmentation and biodiversity: the case for intermediate-sized conservation areas. *Environmental Conservation* 23:4, 290-297.

APPENDICES

Appendix 1

Name of recorder: Ghayyas Ahmad **Date:** **Aug/Sept 2000** **Plot radius: 12m 13m 14.5m**

A. LOCATIONAL DATA

Mosaic ID: **Plot #:** **Transect #: 1 2 3 4** **Transect orientation:**

GPS reading: X=
Y=

B. ENVIRONMENTAL DATA

Elevation: **Aspect:** **N NW NE E** **Site: random gully**
W S SW SE FLAT

	Class		
	0-25%	26-75%	>75%
Slope			

C. BIOLOGICAL DATA

	Average height (m)		
	<3	3-6	>6
Tree layer			

Strata	% cover				
	0-5	6-25	26-50	51-75	>75
Tree layer					
Shrub layer					

Appendix-1 cont.

Climax spp.	#	Regeneration (<0.5m) Y/N
Tree #1 (Olea ferruginea)		
Tree #2 (Acacia modesta)		
Shrub #1 (Dodonaea viscosa)	Y/N	
Shrub #2 (Gymnosporia royleana)	Y/N	

Rare spp.	#	Any other major tree spp. seen
Trees (Pistacia integerrima/Tecoma undulata)		
Shrub (Monotheca buxifolia)	Y/N	

D. HISTORICAL/DISTURBANCE DATA

Invasive spp.	Y/N
Tree (Prosopis juliflora)	
Shrub (Adhatoda vasica)	

Wood debris on ground	**High**	**Moderate**	**Low**
Soil erosion	**High**	**Moderate**	**Low**
Grazing/browsing	**High**	**Moderate**	**Low**
Signs of fire	**Y/N**		
Fresh lopping/stumps	**Y/N**		

Appendix-1 cont.

ALONG TRANSECT RECORDINGS (VISUAL ENCOUNTER SURVEY)

Date: Aug/Sept. 2000
Mosaic ID: Transect #: 1 2 3 4 From plot #: to plot #:

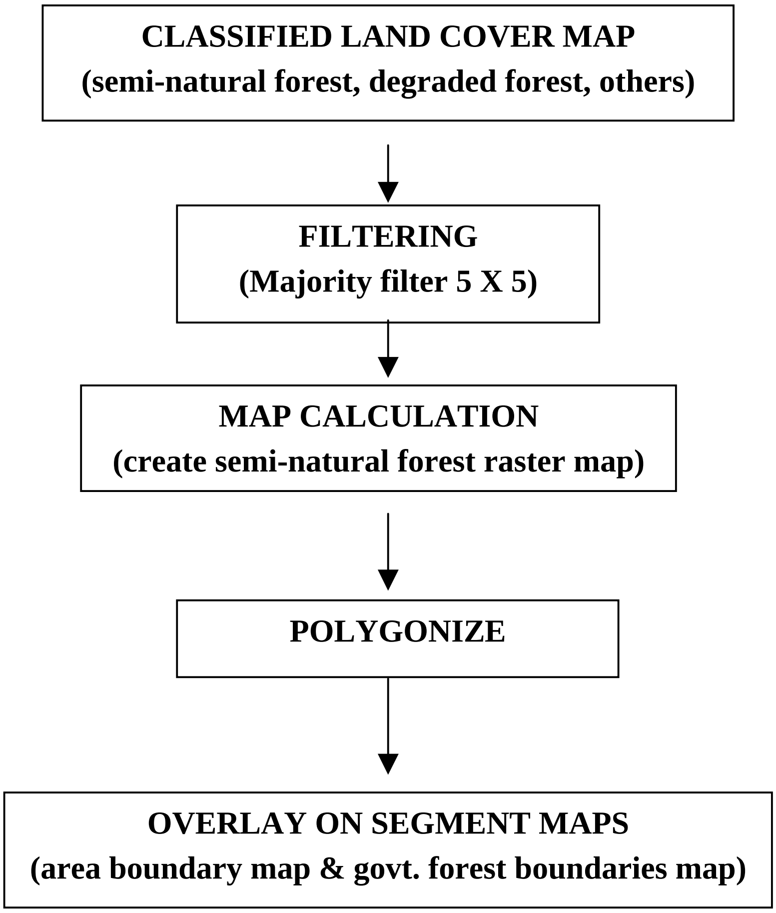
Wolf tree/snag (A.M/O.F) #

Rare tree spp. (P.I/T.U) #:

Remarks: ______________________________

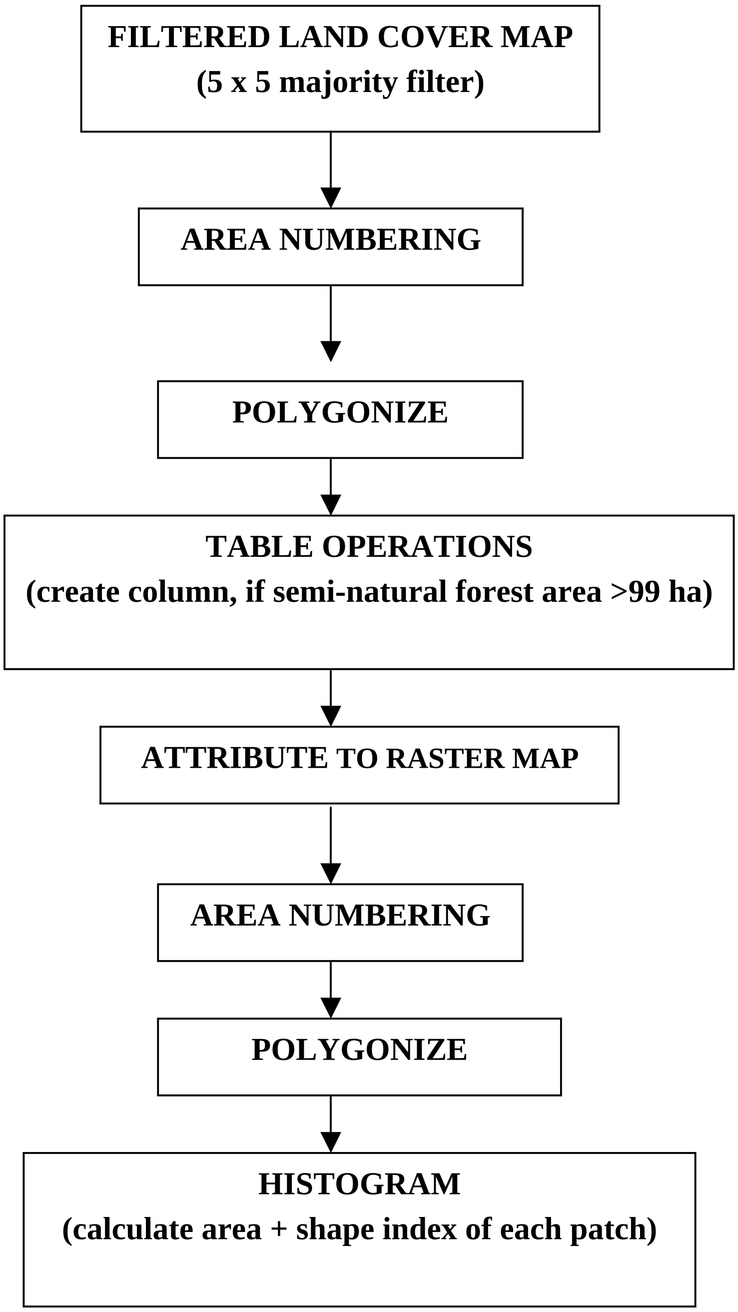
Appendix 2

GIS procedures done in ILWIS to make a map showing the distribution of semi-natural forests



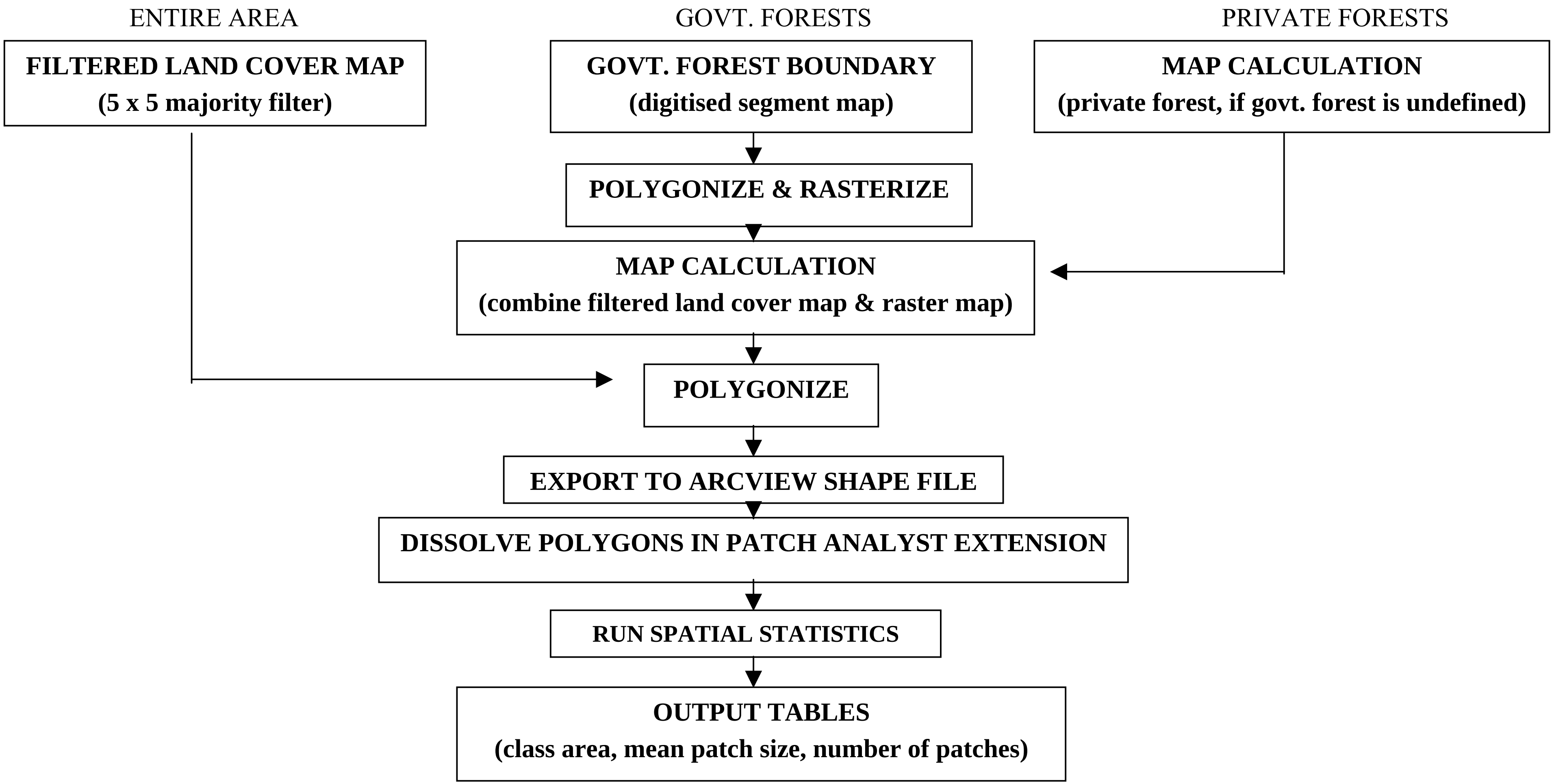
Appendix 3

GIS procedures done in ILWIS to identify priority semi-natural forest patches for conservation



Appendix 4

GIS procedures involved in computing patch statistics in ILWIS and ARCVIEW



Appendix 5

GIS procedures done in ILWIS to calculate

1. *% forest class area in each distance to road class*
2. *# of small (<5 ha) patches in each distance to road class*