IDENTIFYING PRIORITY FOREST AREAS IN THE SALT RANGE OF PAKISTAN FOR BIODIVERSITY CONSERVATION PLANNING USING REMOTE SENSING AND GIS

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Abstract

The Salt Range area of 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.

Major forest mosaics of the area were identified from satellite image and then visited on the ground to collect locational, environmental, and biological data. Field data collection was done through Line transect sampling design. Image classification was performed by using the Supervised and Knowledge-based classification methods. Patch size of the remaining semi-natural forests was selected as the most important criterion for the identification of priority areas. However, patch shape index was also measured.

NDVI (Normalized difference vegetation index) was found to be a good predictor of forest vegetation of the area, particularly, when remote-sensing data is collected during summer rainy season as in this study. Results of image classification obtained by using NDVI were comparable to those obtained by using all spectral bands of the Landsat TM satellite image. However, for the drier western forests of the study area, classification accuracy was quite low.

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.

Introduction

From an economic point of view, dry shrub forests such as the scrub forests of Pakistan are not considered 'valuable' as timber is not the major product (Borota, 1991). However, these forests serve the local communities by

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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.

Shrub forests (Dry sub-tropical broad-leaved and Dry tropical thorn forests) are the second largest forest type in Pakistan (Jan, 1993; Sheikh, 1987). 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.

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. Noss (1990) states that RS and GIS tools could be used for inventorying, monitoring and assessing terrestrial biodiversity at regional landscape and community-ecosystem levels. Gap analysis technique developed by Scott et al. (1993) is a GIS based method to identify gaps in the protection network. Recent advancements in RS and GIS technologies have made it possible to measure indicators of forest biodiversity from satellite images (McCormick and Folving, 1998).

Satellite remote sensing is a widely used technique to produce land use and land cover maps and to study vegetation cover. 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.

Degradation and fragmentation of the shrub forest accompanied with loss of forest biodiversity is not a recent phenomenon. It has been going on for many decades now (Champion, Seth and Khattak, 1965). 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. Despite 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 (The News, 1997). No distinction was made between semi-natural and degraded government forests. All government forests whether in good or bad condition were included in the reserve. 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.

This study has two objectives, which are:

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.

Methods and Materials

- *Study Area and the forests*

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. 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° E to 73°-6'-57" E longitude and between 32° –31'-6" N to 32° –51' –21" N latitude. Study area is over 2300 square kilometers in size.

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 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). Local communities use several medicinal plant species. A detailed survey of the plant wealth of the area is however, lacking. The area is also reasonably rich in faunal resources (Roberts, 1977; Roberts, 1991).

To protect local biodiversity there are five protected areas (WCMC, 1991; Jan, 1993) in the tract at the moment. 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).

- *Site selection for field data collection*

First of all, the study area was identified on a 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 software, 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 green biomass production is at its peak. This is the best season for acquiring digital data for the purposes of forest vegetation detection, as most of the farmlands are crop less during summer season, except those near the lakes that use ground water for irrigation.

As NDVI (normalized difference vegetation index) is the most widely used vegetation index in satellite remote sensing, therefore, an NDVI map of the study area was produced by applying the following formula.

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

where

NIR is the near infra-red band i.e. TM4, and R is the red band i.e. TM3 of the satellite image.

Thereafter, aggregate map operation in ILWIS was applied to the NDVI image. 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.

In the resultant NDVI map, pixel digital number (DN) ranged from 0 to 255. Applying Groten, Immerzeel and Leeuwen (1999) rule, pixels with DN greater than 135 supposedly indicate higher green biomass, which could either be a forest or a cultivated land or an orchard. DN values less than 135 probably 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 thus identified on the imagery.

The false colour composite image was prepared using bands TM4, TM3, and TM2 to aid in visual interpretation 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 13 major forest areas on the image, which were to be visited in the field for data collection.

- *Sampling design, sample size, and plot size and shape*

Systematic sampling design was adopted for this study which involves the location of sample plots at regular intervals (Kent and Coker, 1992). In this design the first sample plot is located at random and subsequent sample plots are laid out at fixed intervals. Later on, after the fieldwork was over, a geo-referenced and atmospherically corrected copy of the same imagery was obtained from WWF-Pakistan. The geo-referenced image was then used in further processing of the remote sensing data.

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. But, as almost all the gullies in the area are dry through out the year (Said, 1956) therefore, in general, vegetation characteristics of gully sites were not expected to be significantly different from non-gully sites.

Out of the 13 larger forest areas that were initially identified for field data collection, 8 were visited during fieldwork. The length of transects 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. 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.

Circular plots of 450 m^2 area, which gives a radius of 11.97 meters or roughly 12 meters for the plot, were laid out. Plot size and shape were chosen from Kent and Coker (1992).

- *Data collected in sample plots*

The following types of measurements were recorded in the sample plots:

GPS reading

A Garmin 12 XL GPS (global positioning system) device was used to record co-ordinates of the centre of each 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 software.

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.

Plots 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.

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. Three height classes were recorded i.e. up to 3m, 3-6m, and over 6m. Mean plot tree height was estimated ocularly.

Plots tree canopy cover

Plot tree canopy cover were estimated visually 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.

- *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.

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

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.

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.

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). 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.

The above criteria was adopted for the forests of the eastern part of the Salt range, which receive more rainfall and hence the vegetation is more luxuriant (Said, 1956). This fact is also confirmed by the following table which gives average annual rainfall data (1985-1995) for three towns that are situated in the east, center and west of the Salt range tract, respectively.

Table 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	Center	740 mm
Mianwali	West	592 mm

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

As for the forests of the western part, they may be regarded as dry forests owing to the lesser amount of annual rainfall received. Such forests are therefore more sparse, low in height and probably low in diversity also. This fact demands that more flexible criteria for classifying the semi-natural forests of the western Salt range be applied. Keeping in view these characteristics of the western forests, the set of criteria was revised for the these forests, which is given below:

1. Mean plot tree height > 3m.
2. Plot tree canopy cover > 25 %, 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 classified as degraded forest. Under these criteria of classification, it is possible that some areas that are actually 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.

- *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.

In the case of NDVI, the theoretical range of values is between –1 to +1. Actually measured value ranges 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, else 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.

Thereafter 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. The maximum likelihood classifier is the most common supervised classification rule used with remote sensing image data. The 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.

- *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). The simplest descriptive statistics is called 'overall accuracy', which is expressed in percentage.

In this study, the classification of the satellite image as well as its accuracy assessment were done separately for the eastern and the western forests. The motorway, which passes approximately through the central part of the Salt range, was chosen as the dividing line between the eastern and the western parts.

- *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.

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. Turner and Corlett (1996) make a strong case for increased persistence of plant species in fragments as small as 100 ha.

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.

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.
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:

Shape index = (perimeter)^2/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 a higher shape index.

- *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 published by the Survey of Pakistan.

Results and Discussion

- *Image classification*

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

First of all, knowledge-based classification rules (explained earlier) 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.

Supervised image classification method was subsequently 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 reason for selecting these three bands was that in remote sensing NDVI is widely applied in studying vegetation characteristics.

The overall accuracy of the classified maps was measured through confusion matrices, which were 85.3% and 58.4% for the eastern and the western forests, respectively.

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.

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. The results for overall accuracy now improved slightly for the western part (61.2%) and were still fairly high (82.2%) for the eastern part. Therefore, in this study results of 6-band classification have been adopted.

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).

- *Priority semi-natural forest patches for conservation*

Identification of priority semi-natural forest patches for conservation was the ultimate objective of this study (GIS procedures illustrated in Appendix). 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 (statistics calculated by using Patch Analyst software in ArcView software's vector theme) which are quite small sizes from conservation viewpoint (Laurance et al., 1997). But they also stress that it should not be considered as a hard and fast rule since even smaller forest patches may have important biological values.

As explained earlier, in this study a minimum patch size of 100 ha was chosen as the standard for the optimum conservation of biodiversity. 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 2 and 3, respectively.

As shown in the tables, shape index for each patch was also computed. 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 higher conservation values. 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. A map showing the identified priority forest patches for conservation is given in figure 1.

Table 2: Details of priority forest patches of the eastern part for conservation.

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

* includes a 30 ha orchard

Coordinates: Projection-Lambert Conformal Conic, Spheroid-Everest, Datum-Indian (Bangladesh).

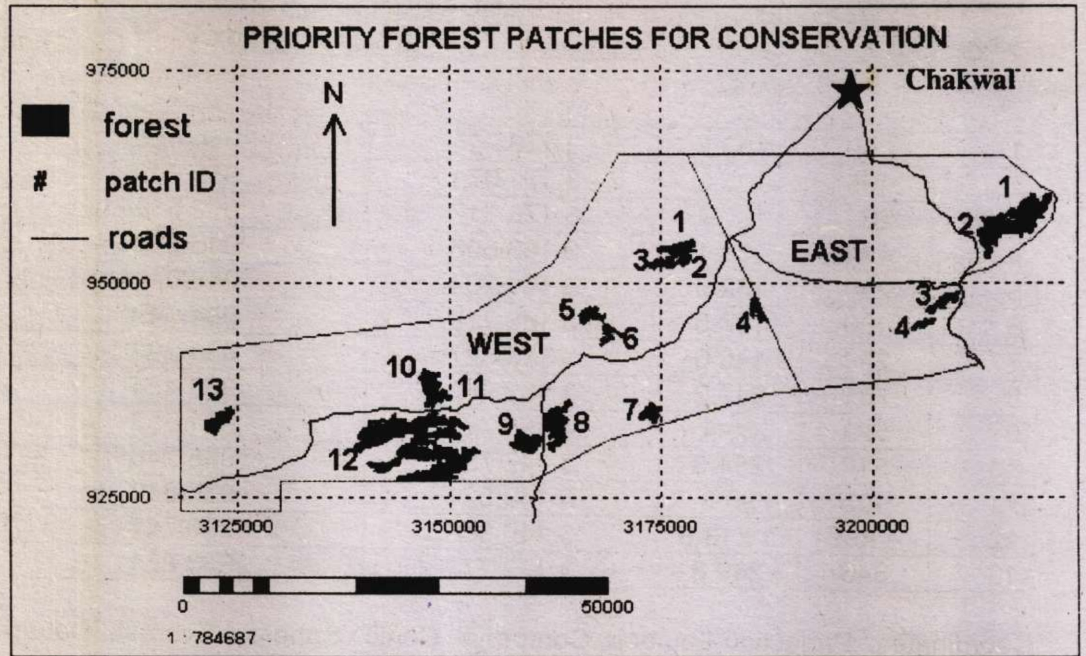
Table 3: Details of priority forest patches of the western part for conservation.

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

Coordinates: Projection-Lambert Conformal Conic, Spheroid-Everest, Datum-Indian (Bangladesh)

As shown in the tables, 4 semi-natural forest patches were identified in the eastern part and 13 in the western part according to the criteria described earlier. These criteria are mainly based on semi-natural forest patch size, which in this case was a minimum of 100 ha. Obviously, 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 as used in this study. Therefore, the selection of any other suitable criteria for biodiversity conservation may give results that are different from the results of this study.

Figure 1: Map showing priority forest patches of the central Salt range identified for conservation



Coordinates: Lambert Conformal Conic

Conclusion

- 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. Remote-sensing data of a higher resolution such as SPOT may also give better results.
- There are a large number of semi-natural forest patches in the area. Smallest of which 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 to disturbance gradients is worth considering. Unless detailed local research is conducted to ascertain the optimum patch attributes for effecti ve 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.

- 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 the Salt range, topographic information is required for image geo-referencing, construction of a DEM, and identification of priority areas and it 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.

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APPENDIX

GIS PROCEDURES DONE IN ILWIS TO IDENTIFY PRIORITY SEMI-NATURAL FOREST PATCHES FOR CONSERVATION