DEVELOPMENT OF A SPATIAL DATABASE IN GEOGRAPHICAL INFORMATION SYSTEM (GIS) DOMAIN FOR NATURAL RESOURCE ASSESSMENT AND MANAGEMENT IN TADOBA - ANDHARI TIGER RESERVE, MAHARASHTRA

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Introduction

The overarching aim of development of spatial database of Tadoba - Andhari Tiger Reserve is the long-term conservation of its floral and faunal diversity along with other natural resources occurring within the reserve. This paper seeks to demonstrate the utility of GIS technology in conjunction with Remote Sensing for resource mapping and its application for enhancing management decision support capabilities.

The Protected Area Network in India comprising National Parks (NPs) and Wildlife Sanctuaries (WLS) has grown steadily; from 10 National Parks and 127 Sanctuaries covering an area of 25,000 km^2 in 1970 to 86 National Parks and 480 Sanctuaries covering an area of 1,53,000.34 km^2 (Rodgers *et al.*, 2000). Yet only few of them have been able to develop and establish a systematic procedure for data collection and analysis on ecological and non-ecological parameters, which are of relevance for the effective resource management in these areas.

Protected Area planning is a process that provides an established framework for consistent and systematic planning, development and administration of the park resources, programmes and facilities (Kesley, 1985). Detailed inventories and analysis are required to determine what infrastructural developments are needed, how they fit into the character of the site and what limitations are presented by the site resources (Raymond, 1987).

Databases are an important way of organising and analysing large amount of information. The Geographic Information System (GIS) is described as "An organised collection of computer hardware, software, geographic data designed to efficiently capture, store, update and analyse all forms of geographically referenced data".

Computers are quite powerful tools which facilitate the decision making process. Feedback and feed forward information can be used iteratively to improve the planning process (Giles and Fujita, 1989). Natural resource planners require information on geophysical attributes, socio-economic aspects of land use in and around protected areas and the animal/plant communities. The most pressing problem faced by the management is the lack of reliable information, lack of funds and insufficient staff to process whatever information is available (Yonzon *et al.*, 1991). For effective planning and in order to overcome these problems, tools are required for analysing and updating spatial information quickly and efficiently.

Geographic Information Systems (GIS) utilise computer based techniques for collating, displaying and overlaying multiple data layers. Because the GIS contains spatially and geographically referenced information, any combination of data at any scale can be viewed. GIS provides the ability to produce outputs at all stages of planning. Because resources are never static and the conceptual plan is in constant state of change, it is important to be able to update and repeat analysis. GIS has been widely used to model the habitat requirements of a wide range of species (Parihar *et al.*, 1986; Tomlin *et al.*, 1987; Young *et al.*, 1987; Hodgson *et al.*, 1988; Agee *et al.*, 1989; Yonzon *et al.*, 1991; Skidmore *et al.*, 1996; Porwal *et al.*, 1996; Mathur and Naithani, 1999; Naithani, 2000). The GIS thus allows optimum site location for various developments including optimising linear feature developments such as creation of roads and nature trails. The GIS analysis is dynamic and can be used in a predictive way. Spatial data layers and large amount of attribute data can not only be linked together but also be used to generate scenarios which are easy to visualise and understand.

In order to achieve a better understanding of the process in which natural systems operate, the application of GIS technology in conjunction with remote sensing is getting wide acceptability (Root *et al.*, 1986; Burrogh, 1990; Yonzon *et al.*, 1991; Karale, 1992; Natrajan, 1992; Dabral, 1992; Legg, 1995; Palihawadana, 1995; Legg and Jewell, 1995; Prasad, 1998; Prasad *et al.*, 1998; Pabla, 1998; Dubey, 1999; Naithani, 2000).

In this study a total of 48 themes depicting the availability, distribution and extent/abundance of physical and ecological attributes of the study area were derived using GIS technology. The various thematic data layers generated through this study provide valuable assistance in the assessment, management and monitoring of PA resources.

Study Area

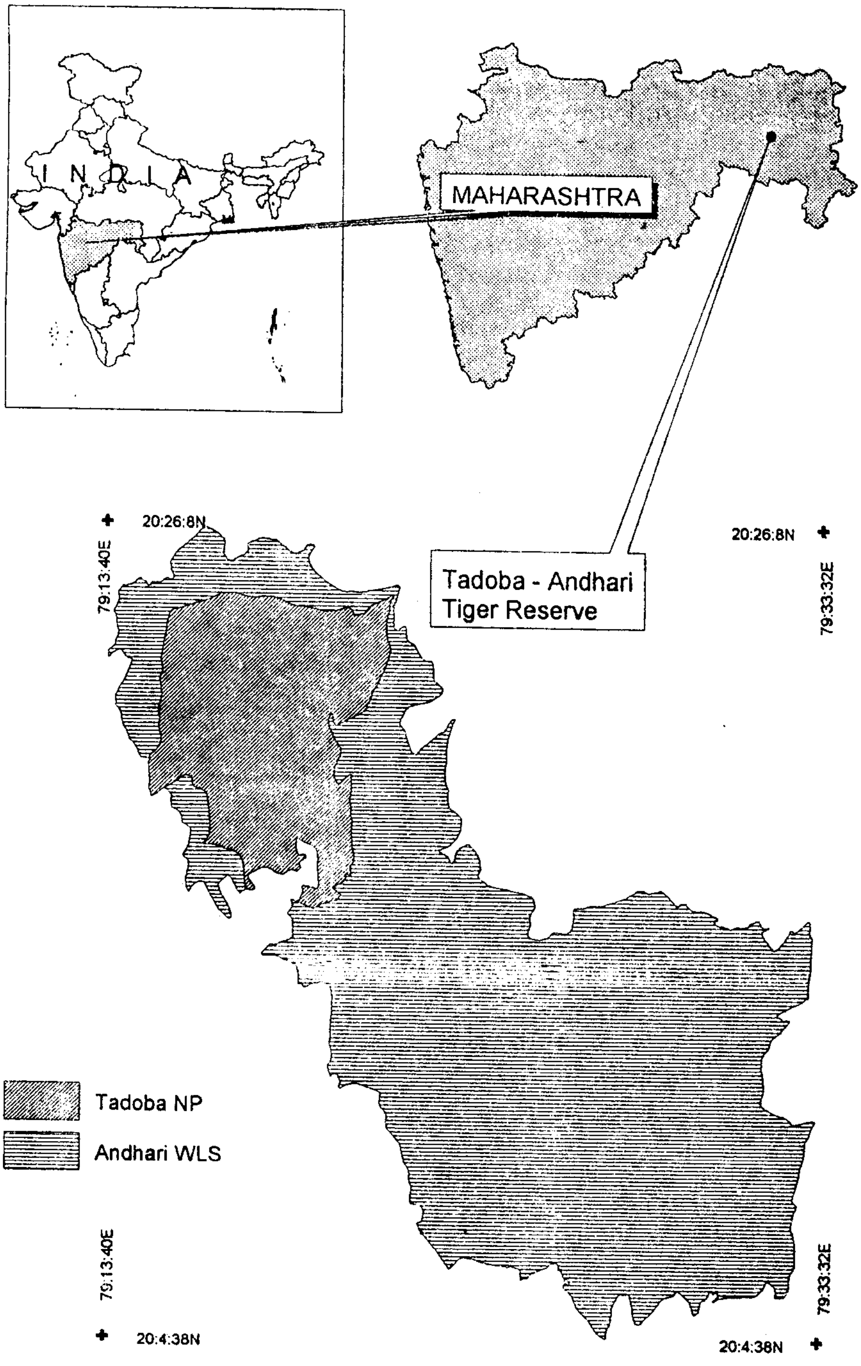
Tadoba-Andhari Tiger Reserve (TATR) is situated in the civil district of Chandrapur, Maharashtra State (Fig. 1). This area of Maharashtra is known as Vidharbha region. The area lies between 20°-04'.53"N to 28°-25'.51"N latitude to 79°-13'.13"E to 79°-33'. 34"E longitude.

Extent of the total area of the TATR is 619.76 km^2, out of which Tadoba National Park comprises of 116.54 km^2 and the remaining 503.22 km^2 forms Andhari Wildlife Sanctuary.

Methods

The methodology mainly involved the input of spatial data concerning various map layers and associated attribute data. Attribute data was analysed along with spatial data layers to produce result oriented derived thematic maps. The main sources of spatial data were the Survey of India (SOI) 1:50,000 toposheets, satellite imagery (IRS IB, LISS-II) geocoded False Colour Composites, Global Positioning System (GPS) data, field data collected during study period and ancillary data taken from Forest Department records.

Fig. 1



Location Map of Tadoba-Andhari Tiger Reserve

The spatial data layers like road, drainage, settlements, contours, boundaries were taken from SOI toposheets. One of the most important data layers on vegetation was derived from satellite image. This data was obtained from National Remote Sensing Agency (NRSA), Hyderabad. The data relating to fire, grazing, human impact zones and water availability was generated through field study and in certain cases data was extracted from old records to determine the trends.

All the maps were digitised in Geographic Resource Analysis Support System (GRASS 4.0) software on UNIX based Workstation using Calcomp digitizer. The attribute data was stored in Foxbase software and the analysis was performed using SPSS+ software. For analysis of spatial data GRASS 4.0, GRASS 4.1 and ARC/INFO softwares were used. The entire geophysical database was ported on Sun Sparc 2 Work Station for spatial analysis.

Results and Discussion

Forest Resource Mapping : Forest are one the important resources on earth for the sustenance of wildlife and human beings (Lal, 1989). Reliable and precise information of these resources is required for careful planning. To assess the availability of resource we need to use a technology, which can give this information with precision. Remote Sensing technology has given an impetus to resource mapping and monitoring (Lillisand and Kiefer, 1979; Curran, 1985; Lal *et al.*, 1991; Karale, 1992; Vijayakumaran and Menon, 1998; Prasad, 1998; Prasad *et al.*, 1998). Space borne techniques are now widely used in vegetation mapping and distribution (Tomar and Maslekar, 1974; Lakshmi *et al.*, 1988; Root *et al.*, 1986; Kushwaha and Madhavan, 1986; Madhavan *et al.*, 1986; Roy *et al.*, 1986; Shedha *et al.*, 1986; Parihar *et al.*, 1986; Porwal and Roy, 1991; Anon., 1994). A total of fifteen vegetation types were delineated from the satellite image (IRS IB LISS II, 1994) (Table 1). Vegetation *mapping was done at 1:50,000 scale.* Vegetation map at this scale was considered appropriate to document the vegetation of the reserve. The dominance, structure and composition of plant species formed the mapping criteria along with site factors. The forest cover was mapped based on the tonal and textural patterns obtained from satellite image. Important resources like grasslands, which play a significant role in providing forage for wild ungulates, were also mapped using remote sensing. These

Table 1

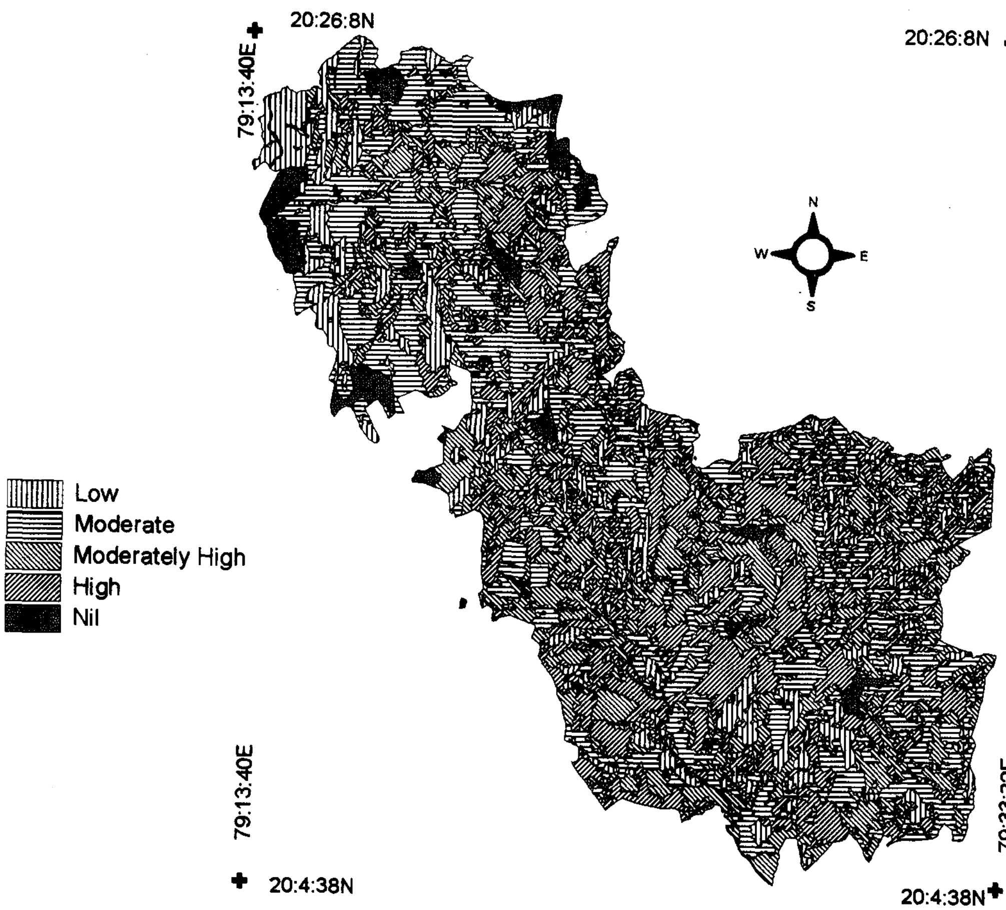
Area of different vegetation types in Tadoba-Andhari Tiger Reserve

Vegetation Type	Area (km^2)	%
Teak-1 (>40% crown cover)	18.72	3.04
Teak-2 (<40% crown cover)	76.80	12.45
Teak-Bamboo	21.80	3.54
Teak *Miscellaneous* Bamboo	*133.70*	*21.65*
Miscellaneous	33.30	5.39
Miscellaneous-Bamboo I (crown cover 40-60%)	156.02	25.27
Miscellaneous-Bamboo II (crown cover <40%)	129.70	21.01
Riparian	1.60	0.26
Grassy Meadows	0.84	0.14
Grassland on Plateau	2.80	0.45
Scrub	7.90	1.17
Miscellaneous Open	9.80	1.59
Agriculture Areas	15.10	2.45
Human Settlement	8.16	1.32
Water Bodies	1.70	0.28
Total	617.94	100

grasslands are very small in size but nonetheless offer great deal of support to wildlife in terms of forage and cover. Grasslands form 0.6 % of the total geographic area of TATR. Bamboo was recognised as yet another resource important for wildlife as it provides food and shelter to a range of wild animals found in the reserve. Bamboo distribution was mapped based on the image interpretation along with ground data. Areas under Very dense, Dense, Medium and Sparse bamboo distribution come to 46%, 24%, 12% and 13% respectively. The total area under bamboo comes to 95%.

Animal Distribution and Abundance : Animals form a major component for management in a protected area management system. Since the main thrust of protected area management is on managing the animal populations it

Fig. 2 (a)



Gaur distribution and abundance map of TATR becomes important to know how the animal populations are distributed in landscape in relation to vegetation communities. Direct observations and indirect evidences were taken as key variables in deriving these maps. The data from direct sightings and indirect evidences were grouped into different level of abundance categories as Very High, High, Medium, Low and Absent. These abundance values were spatially integrated with the habitat map to produce the distribution and abundance maps for seven species of ungulates, which are of management significance (Fig. 2a).

Large carnivores like Tiger and Leopard require maximum attention in terms of management as they are considered as keystone species and are higher order predators in the food chain. These carnivores help in maintaining the populations of herbivores. Apart from direct sightings, data was collected through indirect evidences such as scats, kills, pugmarks, scrape signs and claw marks. This helped in generating a spatial distribution pattern of these two species of large cats in the study area. Data on all the above mentioned parameters was aggregated to develop an index for distribution in terms of low, medium and high categories, in GIS domain using ARC/INFO. The overall Tiger distribution appeared to be clumped. Tiger distribution based on the above information when mapped revealed the population to be distributed in 69.8% of the total geographical area of the reserve. Leopard population on the other hand was distributed in only 48.6% of the total geographical area of the reserve. Leopards avoided the areas, which were under heavy use by tigers. Leopards in TATR mainly take respite in peripheral areas and close to villages inside the reserve.

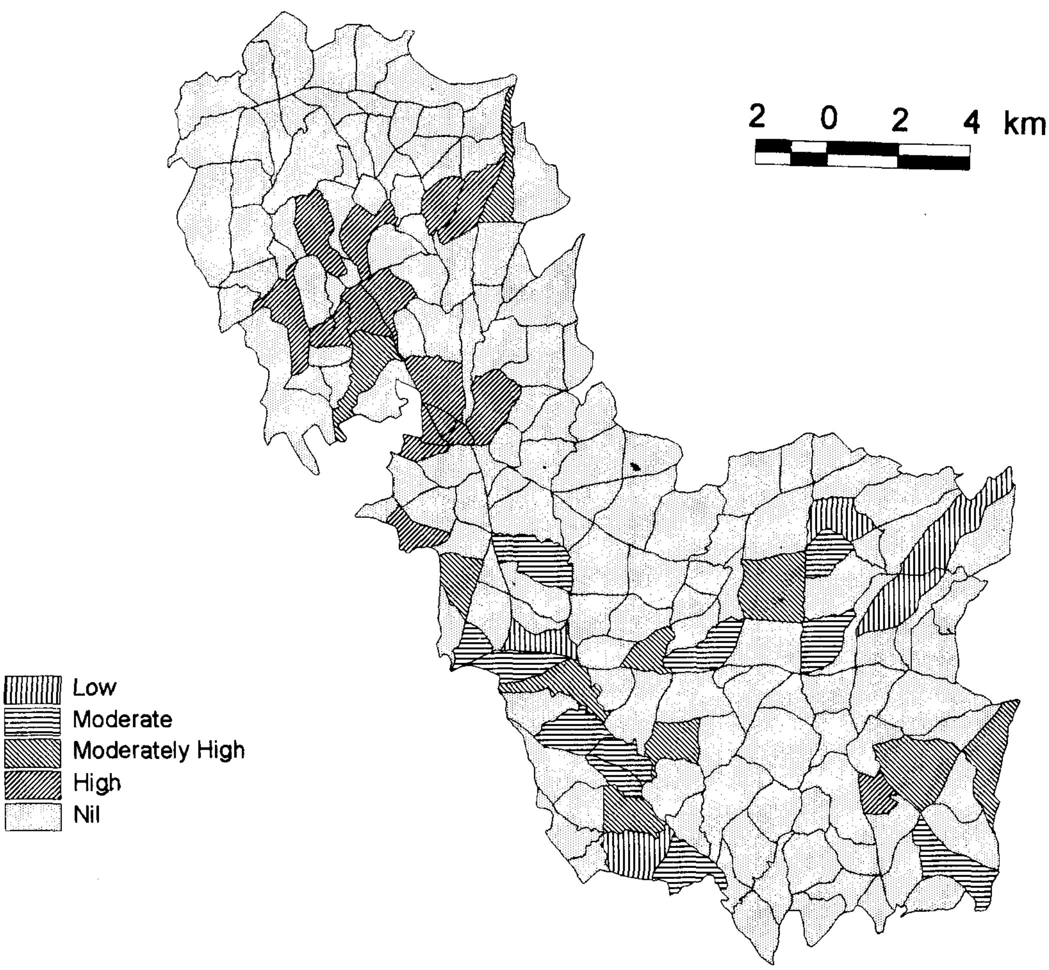
Spatial Database and Resource Mapping : Administrative maps showing different compartments, beats, round and ranges were produced from maps provided by Forest Department. These maps were rectified using Survey of India (SOI) toposheets of the area. Areas falling under Reserve Forest, Protected Forest and Non-forest enclaves were delineated from satellite image. Topographic maps were prepared using SOI map and were then digitised.

Digital Terrain Model (DTM) was generated through routing algorithm, which is inbuilt in software. It does so by calculating neighbourhood attributes i.e., attributes, which can be calculated by using height information from neighbouring points (Desmet and Govers, 1996). DTMs have been widely used by land managers and hydrologists for various things like determining flow paths (Lea, 1992), calculating upslope areas (Jenson and Domingue, 1988), drainage network detection (Mark, 1984) and identifying and delineating catchment areas (O' Callaghan and Mark, 1984). The DTM was prepared at 20m contour interval. These DTMs can also be used to prepare interpretative models for visitors and can be useful in planning other developments like construction of roads and nature trails inside the reserve.

Road network was digitized from SOI 1:50,000 scale toposheets and Forest Department maps on the same scale. Roads are an integral part of any protected area management system as they are used for tourism and patrolling activities. It is important to be able to plan out tourism and patrolling strategies properly and for these, road forms the primary layer for analysis.

Water Resources : Primary, secondary and tertiary drainage network was derived from existing SOI maps. Drainage maps can be very useful in planning soil and moisture conservation works, which are carried out in most of the National Parks and Sanctuaries. Water sources are an important asset in any dry deciduous ecosystem. Animals move large distances in search of water in lean season and are forced to move to the regions with open water areas (Jarman, 1972; Jarman and Jarman, 1973; Western, 1975; Fryxell and Sinclair, 1988; Williamson *et al.*, 1988; Rautenstrauch and Krausman, 1989). It is therefore important for management to have a clear picture of water availability in the protected area so that animals can be prevented from moving outside the PA boundary, where they become susceptible to poaching and other threats. Water resource management is therefore a priority

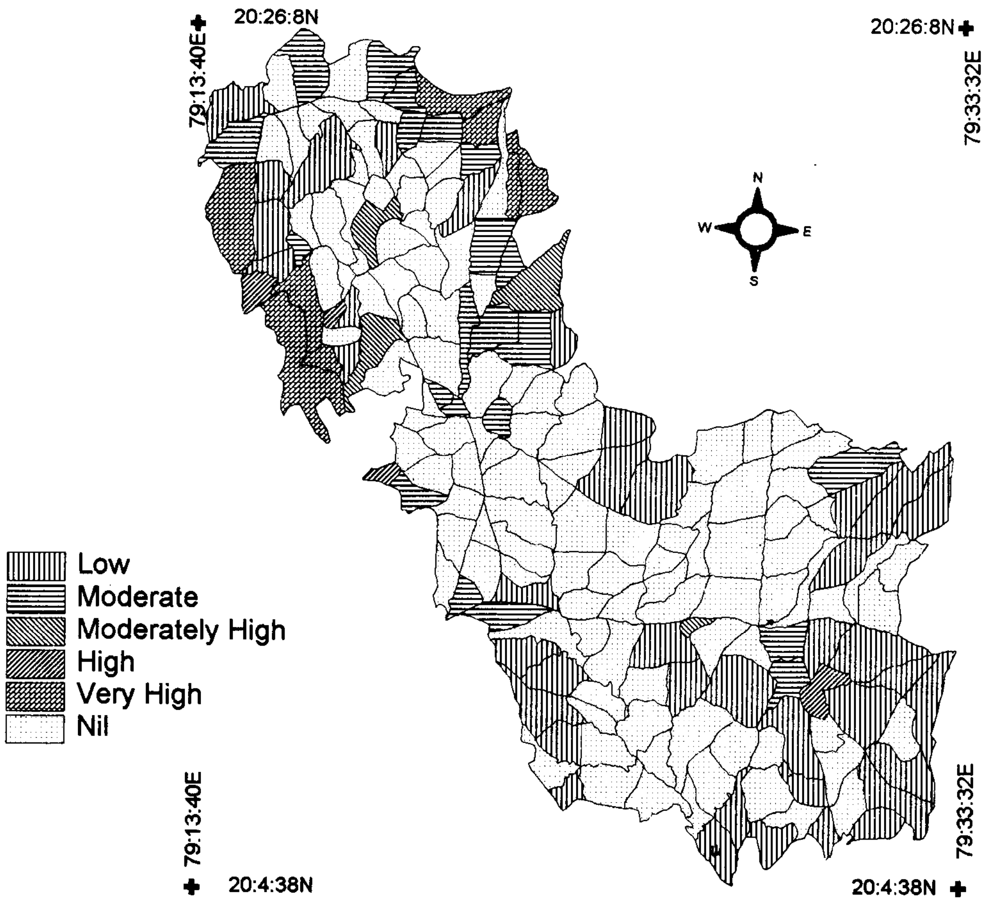
Fig. 2 (b)



Saltlick distribution and usage map of TATR

work in dry seasons in most of the protected areas. In extremely dry years even the permanent water holes and streams dry up resulting in large number of animal mortality (Anon. 1961; Owaga, 1975; Williamson and Mbano, 1988). The water sources are also frequented by predators, as apart from meeting their water requirement they also need to cool their bodies and the chances of successful predation also increases as large number of herbivores tend to congregate in such areas (Bourliere 1963; Ayeni, 1975; Elliot *et al*, 1977). To map the distribution of water in the reserve initially all artificial water holes were mapped using a Global Positioning System (GPS). Subsequently, compartment wise survey was done so as to cover all compartments of TATR and data on water availability was collected for two years i.e., from January 1996 to December 1997. This data was spatially analysed to generate the water scarcity map.

Fig. 2 (c)



Anthropogenic disturbance map of TATR

Salt-lick Distribution : Salt licks are places where animals ingest the soil, which is rich in salts to replenish their salt deficiency. Large number of ungulates and birds are known to visit salt licks (Jarman, 1972). Salt-licks are found naturally as well are created artificially by putting salt blocks in different areas, normally close to the water sources. To select sites to create artificial salt-licks it is important to know the spatial distribution of natural ones and then accordingly decide the new areas. Compartment-wise survey was undertaken for this and all natural salt-licks as well as artificial ones were recorded. Data was also collected on the use of these salt-licks by wild animals, based on direct and indirect evidences for one year (1996 - 1997). This data was later summarised into four usage categories *viz.* Low, Moderate, Moderately high and High (Fig. 2b).

Livestock Grazing : Data on livestock grazing was collected partly by field study and partly through the information provided by game guards of the respective beats, based on their perception and field observations. This map was created through the data collected from each compartment during routine work by recording all observations on encounter of livestock dung and livestock. The areas under low, medium and high grazing, as per the map are 5%, 4% and 14% respectively. It is evident that 77% of TATR area is free from livestock grazing.

Human Disturbance : Despite the best efforts by protected area management it is virtually impossible to eliminate the adverse impacts of human habitations on PA resources. Observations of lopping signs and direct encounter of people in the forest were recorded compartment-wise and later same information was mapped to visualise the spatial pattern and extent of anthropogenic intrusion inside the protected area (Fig. 2c).

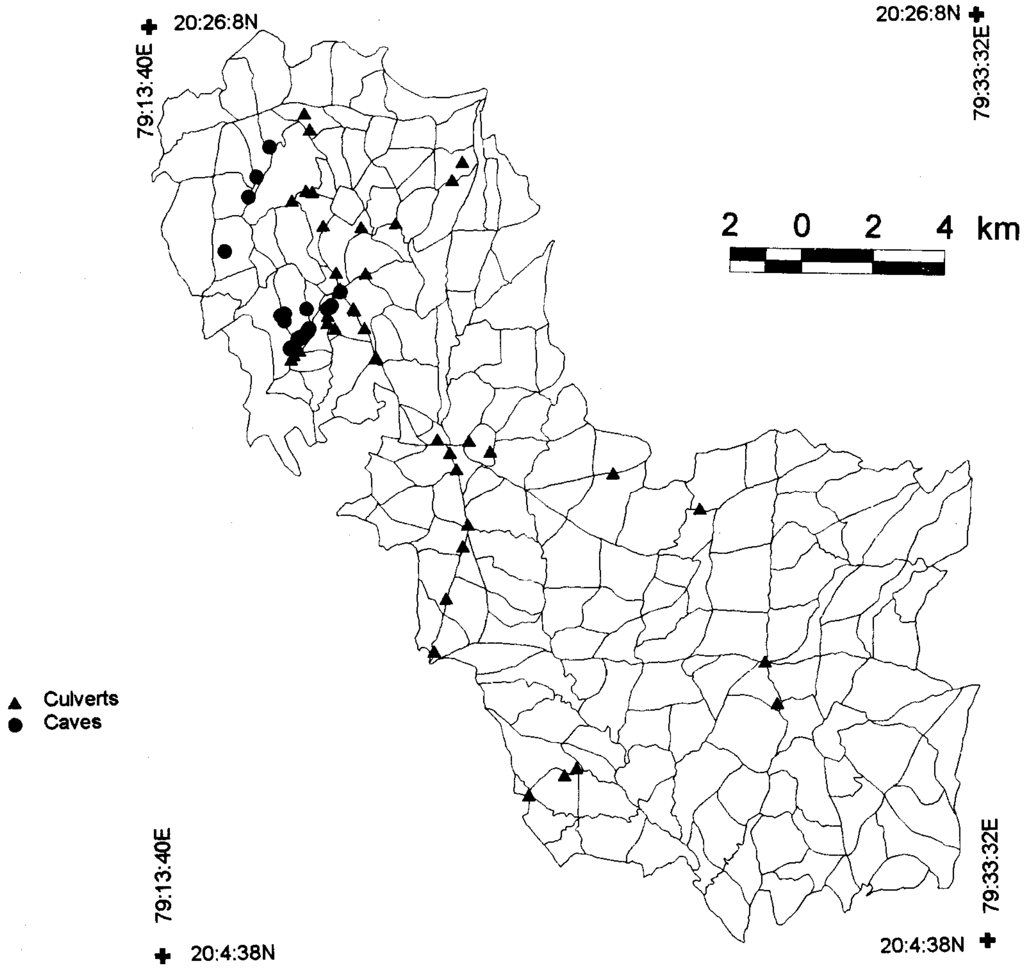
Unique Habitats : Wildlife habitats are invariably identified only with the vegetation communities, but there are some habitats where vegetation association is not obvious. These habitats are represented by geomorphic features with special functions not provided in plant communities or their successional stages (Thomas, 1979) and are called as unique habitats. Unique habitats comprising of caves, cliffs, talus and culverts were monitored for their use by different animal species. All these features were mapped using hand held Global Positioning System (GPS) technology (Fig. 2d). Results suggest that these habitat features are used by a wide range of animals. Bats and Sloth bear were the most frequent user of caves. Tiger used caves only in summers, which could be because of the fact that inside the caves the temperature was lower by 10-15°C compared to outside. Culverts were used mainly by Tiger and Sloth bear. Tiger used culverts throughout the year with an increased use in summer. Culverts were used by a wide group of animals and in all 734 animal tracks were recorded in culverts. These habitat features form an excellent resting and breeding site for different group of species. It is quite evident that the unique habitats perform important functions for a wide range of animals and animal groups. Results indicate that they provide diversity to the environment, which is otherwise dominated by vegetation communities. Though small in extent, these features constitute important microhabitats. This is perhaps for the first time that systematic observations have been made on the unique habitats. Special care needs to be taken regarding these features. Tourism should be discouraged in such areas. Any habitat modification around such habitats should be avoided.

Tourism : TATR is a very popular destination for the tourists especially day visitors from Nagpur and adjoining areas. During the dry season there is a heavy concentration of tourist activity around the Tadoba lake. Visitors move in vehicles accompanied by a guide on specially designated roads. There are trails for use by participants of nature camps and other educational groups. There is a good potential of managing tourism with the help of GIS technology by overlaying the animal distribution maps developed as part of this study on the road network of TATR.

Conclusions

This study has provided extensive

Fig. 2 (d)



Unique habitat map of TATR

datasets on ungulate population structure, distribution, abundance and habitat utilisation patterns, which provide a scientific basis for management of these species and their habitats. The very comprehensive spatial database in GIS domain developed by this study would assist the management in informed decision making and monitoring of various resources.

The study has successfully demonstrated the utility of remote sensing used in conjunction with the GIS technology for mapping and management of natural resources. It is suggested that similar studies are carried out in other PAs so that comprehensive information on PA resources can be generated and used in their management (Mathur, 1991; Pabla, 1998).

Acknowledgements

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SUMMARY

This study was carried out in Tadoba - Andhari Tiger Reserve (TATR) between 1994 and 1999 with specific objective of developing a comprehensive spatial database in Geographic Information System (GIS) domain to assist the management in informed decision making and monitoring of various resources. A 48-layered thematic database covering the administrative, physical, ecological, socio-ecological and management attributes has been developed. The study has also provided extensive datasets on ungulate population structure, distribution, abundance and habitat utilisation patterns, which provide a scientific basis for management of these species and their habitats. The study has also demonstrated the utility of Remote Sensing and GIS technologies used in conjunction for mapping of Protected Area (PA) resources. It is suggested that similar studies should be carried out in other major PAs of the country in order to effectively plan the management and monitoring of resources.

ताडोबा – अन्धेरी बाघ संरक्षित क्षेत्र महाराष्ट्र के प्राकृतिक संसाधन आकलन और प्रबन्ध के भौगोलिक सूचना प्रणाली क्षेत्र में अन्तरिक्ष आंकड़ों – आधार का विकास

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साराशं

यह अध्ययन ताडोबा अन्धेरी बाघ संरक्षित क्षेत्र में 1994 और 1999 के दौरान भौगोलिक सूचना प्रणाली में सर्वसमावेशी अन्तरिक्ष आंकड़ा आधार विकसित करने के विशेष उद्देश्य से किया गया ताकि वहाँ के विभिन्न संसाधनों के बारे में जातकारी भरा निर्णय लेने और पड़ताल करने में सहायता प्रदान की जा सके । 48 स्तरों वाला विषयगत आंकड़ा – आधार जिसमें प्रशासनिक, भौतिक, परिस्थिकीय, समाज – पारिस्थिकीय और प्रबन्ध अंशों को लिया गया था, विकसित किया गया । इस अध्ययन से फटे खुरों वाले प्राणियों की संख्या संरचना, वितरण, प्रचुरता और प्राकृतावास उपयोग सज्जाओं पर भी विस्तृत आंकड़ा – कुलक मिले हैं जो इन जातियों और इनके प्राकृतावासों का प्रबन्ध करने के लिए वैज्ञानिक आधार प्रदान करते हैं । इस अध्ययन ने रक्षित क्षेत्र संसाधनों का मानचित्रण करने में भौगोलिक सूचना प्रणालियों के साथ सुदूर संवेदन प्रविधियों को मिलाकर उपयोग करने की उपयोगिता भी दिखाई है । यह भी सुझाया गया है कि देश के अन्य बड़े रक्षित क्षेत्रों में भी ऐसे ही अध्ययन कराए जाने चाहिए ताकि संसाधनों का प्रबन्ध करने और पड़तालने की योजनाएं प्रभावकारी ढंग से तैयार की जा सकें ।

References

Agee, J.K. and P. Root (1985). Vegetation and fuel mapping of North Cascades National Park, *Final Report*, College of Forest Resources, Seattle.

Agee, J.K., S. Stitt, M. Nyguist and P. Root (1989). A Geographic Analysis of Historical Grizzly Bear Sightings in the North Cascades. *Photgram. Eng. of Remote Sensing*, **55** : 1637-1642.

Anon. (1961). Mounting death toll follows severe draught. *Wildlife* **3** : 22.

Anon. (1994). Forest type mapping, monitoring and habitat suitability analysis of Goral (*Nemorphaedus goral*) using aerospace remote sensing technique and Geographical Information System. *IIRS Report.*

Ayeni, J.S.O (1975). Utilisation of Water Holes in Tsavo National Park (East). *E. Africa Wildlife Journal*, **13** : 305-323.

Bourliere, F. (1963). Conservation and Management of Game Stock. *A Review of the Natural Resources of the African Continent*, UNESCO, Paris. 437pp.

Burrogh, P.A. (1990). *Principles of Geographical Information System for land Resources Assessment*, Clarendon Press, Oxford.

Curran, P.J. (1985). *Principles of Remote Sensing.* Longman, London..

Dabral, S.L. (1992). Use of Remote Sensing in Preparing Stock Maps. *Proc. Silver Jubilee Seminar on Training and Education in Remote Sensing for Resource Management,* Indian Institute of Remote Sensing, Dehra Dun. pp. 168-176.

Desmet, P.J.J. and G. Govers (1996). Comparison of Routing Algorithms for Digital Elevation Models and Their Implications for Predicting Ephemeral Gullies. *International Journal of Geographical Information System.* **10** (3) : 311.

Dubey, Y. (1999). Application of Geographic Information System and Remote Sensing in Assessing Habitat, Resource Availability and its Management in Tadoba-Andhari Tiger Reserve, Maharashtra. *Ph.D. Thesis*, FRI Deemed University, Dehra Dun. pp. 249.

Elliot, J.P., I.M. Cowan and C.S. Holling (1977). Prey Capture by the African Lion. *Canadian Journal of Zoology*, **55** : 1811-1828.

Fryxell, J.M. and A.R.E. Sinclair (1988). Seasonal Migration by White Eared Kob in Relation to Resources. *African Journal of Ecology*, **26**:17-26.

Giles. R.H. Jr. and M.S. Fujita (1989). *Proc. International Conference on National Parks and Protected Areas*, Kuala Lumpur, Malaysia. pp. 11-17.

Hodgson, M., J. Jensen, H. Mackey and M. Coulter (1988). Monitoring of Wood Stork Foraging Habitat Using Remote Sensing and Geographic Information Systems. *Photogram. Eng. Remote Sensing.* **54** : 1601-1607.

Jarman, M.V. and P.J. Jarman (1973). Daily Activity of Impala. *E. African Wildlife Journal*, **11** : 75-92.

Jarman, P.J. (1972). The Use of Drinking Sites, Wallows and Saltlicks by Herbivores in the Flooded Middle Zambesi Valley. *E. African Wildlife Journal*, **10** : 193-209.

Jenson, S.K. and J.O. Domingue (1988). Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing*, **54** : 1593-1600.

Karale, R.L. (1992). Natural Resource Management - A New Perspective. *Natural Resource Management System*, Department of Space, Govt. of India, Banglore.

Kesley, C. (1985). *Master Plan Process for Parks and Recreation.* Reston: Am. Alliance for Health, Physical Education, Rec. and Dance, 1985.

Kushwaha, S. P.S and N.V. Madhavan Unni (1986). Application of remote sensing techniques in forest cover monitoring and habitat evaluation: A case study in Kaziranga National Park, Assam. *Proc. Seminar-cum -workshop on Wildlife Habitat Evaluation using Remote Sensing Techniques*, Dehra Dun. pp. 238-247.

Lakshmi, V. U. and C.B.S. Dutt (1998). Micro-level planning and sustainable forestry through GIS, *Current Science*, **75** (3) : 245-255.

Lakshmi, V.U., M.S.R. Murthy and C.B.S. Dutt (1998). Efficient forest resources management through GIS and remote sensing, *Current Science*, **75** (3) : 272-282.

Lal, J.B. (1989). *India's Forests : Myths and Realities*. Natraj Publishers, Dehra Dun. pp. 304.

Lal, J.B., A.K. Gulati and M.S. Bist (1991). *Int. J. of Remote Sensing*. **12** (3) : 435-443.

Lea, N.J. (1992). An Aspect-Driven Kinematic Routing Algorithm. *Overland Flow, Hydraulics and Erosion Mechanics*. (A.J. Parsons and A.D. Abrahams, Eds.). London: UCL Press. pp. 393-407.

Legg, C. (1995). A Geographic Information System for Planning and Managing the Conservation of Tropical Forests in the Knucles Range. Special Issue of the *Sri Lanka Forester. Journal of Sri Lanka Forest Department*. pp. 37-62.

Legg, C. and N. Jewell (1995). A 1:50,000 Scale Forest Map of Sri Lanka: The Basis for a National Forest Geographic Information System. Special Issue of the *Sri Lanka Forester. Journal of Sri Lanka Forest Department*. pp. 3-21.

Lillisand, T.M. and R.W. Kiefer (1979). *Remote Sensing and Image Interpretation*. (New York: John Wiley).

Madhavan Unni, N.V., K.S. Murthy Naidu and S.P.S. Kushwaha (1986). Monitoring forest cover using satellite remote sensing techniques with special reference to Wildlife Sanctuaries and National parks. *Proc. Seminar-cum workshop on Wildlife Habitat Evaluation using Remote Sensing Techniques*, Dehra Dun. pp. 146-156.

Mark, D.M (1984). Automated Detection of Drainage Networks from Digital Elevation Models. *Cartographica*. **21** : 168-178.

Mathur, V.B. (1991). The ecological interaction between habitat composition, habitat quality and abundance of some wild ungulates in India. *D.Phil. Thesis*. University of Oxford, United Kingdom. 279 pp.

Mathur, V.B. and S. Naithani (1999). Development of a spatial database of the Great Himalayan National Park Conservation Area (GHNPCA) in GIS Domain. Project Report 'An Ecological Study of the Conservation of Biodiversity and Biotic Pressures in the Great Himalayan National Park Conservation Area – An Ecodevelopment Approach'. *FREEP – GHNP Final Project Report*, Wildlife Institute of India, Dehra Dun. Vol. 1 to 6.

Naithani, Suneet (2000). Habitat characterisation in Great Himalayan National Park (GHNP), Himachal Pradesh using Remote Sensing and GIS technologies with special emphasis on geobotanical aspects. *D.Phil. Thesis* submitted to H.N.B. Garhwal University, Srinagar. pp. 150.

Natrajan, C. (1992). Geographic Information System in Resource Management. *Proc. Silver Jubilee Seminar on Training and Education in Remote Sensing for Resource Management*. Indian Institute of Remote Sensing, Dehra Dun. pp. 128-130.

O'Callghan, J.F. and D.M. Mark (1984). The Extraction of Drainage Networks from Digital Elevation Data. *Computer Vision Graphics and Image Processing*. **28** : 323-344.

Owaga, M.L. (1975). The Feeding Ecology of Wildebeest and Zebra in Anthi-Kaputei Plains. *E. Afr. Wildlife Journal*, **13** : 375-383.

Pabla, H.S. (1998). Development of a user-friendly wildlife monitoring methodology for protected areas in India, *Ph.D. Thesis*, Forest Research Institute (Deemed Univ.). pp. 196.

Palihawanda, N. (1995). The Application of Remote Sensing and GIS Techniques for the Detection of Change in Forest Cover. Special Issue of the *Sri Lanka Forester. Journal of the Sri Lanka Forest Department*. pp. 73-77.

Panwar, H.S. and V.B. Mathur (1992). Protected Area Network in India: A Review. *Paper presented in the IV World Parks Congress*, Venezuela.

Parihar, J.S., P.C. Kotwal, S. Panigrahy and N. Chaturvedi (1986). Study of Wildlife habitat using high resolution space photographs. A case study of Kanha National Park. ISRO Special Publication, ISRO-SP-17-86,'*Results from Indo-Soviet remote sensing experiment.* Terra on board Salyut-7.

Porwal, M.C., P.S. Roy and V. Chellamuthu (1996). Wildlife habitat analysis for Sambar (*Cervus unicolor*) in Kanha National Park. *Ont. J. Remote Sensing.* **17** (14) : 2683-2697.

Porwal, M. C. and P.S. Roy (1991). Attempted understorey characterisation using aerial photography in Kanha National Park. Madhya Pradesh, India. *Environmental conservation,* **18** : 45-50

Prasad, N. (1998). Conservation planning for the Western Ghats of Kerela: II. Assessment of habitat loss and degradation, *Current Science,* **75** (3) : 228-235.

Prasad, S.N., L. Vijyan, S. Balachandran, V.S. Ramachandran and C.P.A. Verghese (1998). Conservation planning for the Western Ghats of Kerela: I. A GIS approach for location of biodiversity hot spots, *Current Science,* **75** *(3) : 211-219.*

Rautenstrauch, K.R. and P.R. Krausman (1989). Influence of Water Availability and Rainfall on Movements of Desert Mule Deer. *J. Mamm.* **70** :197-201.

Raymond, S. (1987). College of Forestry. Stephen F. Austin State University, Texas.

Rodgers, W.A., H.S. Panwar and V.B. Mathur (2000). *Wildlife Protected area Network in India: A review* (Executive summary). Wildlife Institute of India, Dehra Dun.

Root, R.R., S.C.F. Stitt, M.O. Nyquist, G.S. Waggoner and J.K. Agee (1986). Vegetation and Fire Fuel Models Mapping of North Cascades National Park. ACSM-ASPRS. *Annual Convention Tech.* **3** : 78-85.

Roy, P.S., K.G. Saxena, D.N. Pant and P.C. Kotwal (1986). Analysis of vegetation types using remote sensing techniques for Wildlife habitat evaluation in Kanha National Park. *Proc. Semina-cum-workshop on Wildlife Habitat Evaluation using Remote Sensing Techniques,* Dehra Dun. pp. 83-116.

Shedha, M.D., M.C. Porwal and Indrajit Singh (1986). Aerial remote sensing techniques for habitat mapping, monitoring changes in habitat and planning roads and tracks. *Proc. Seminar-cum-workshop on Wildlife Habitat Evaluation using Remote Sensing Techniques,* Dehra Dun. pp. 183-192.

Skidmore, A.K., A.Gaul and P. Walker (1996). Classification of Kangaroo Habitat Distribution Using Three GIS Models. *International Journal of Geographical Information System.* **10** : *441-454.*

Tomar, M.S. and A.R. Maslekar (1974). *Aerial photographs in landuse and forest surveys.* Jugal Kishore & Co, Dehra Dun.

Tomlin, S.D., S.H. Berwick and S.M. Tomlin (1987). The Use of Computer Graphics in Deer Habitat Evaluation. *Geographic Information Systems for Resource Management: A Compendium.* (W. Ripple, Ed.) American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping, Falls Church, VA. pp. 145-146.

Thomas, J.W. (1979). *Wildlife habitats in managed forests: the blue mountains of Oregon and Washington* (J. Thomas, Ed.). Wildlife Management Institute, Washington DC. pp. 512.

Vijayakumaran, P. and A.R.R. Menon (1998). Estimation of Bamboo Resources in Kerela by remote sensing techniques, *Current Science,* **75** (3) : 209-210.

Western, D. (1975). Water Availability and its Influence on the Structure and Dynamics of a Savannah Large Mammal Community. *E. Afr. Wildlife Journal.* **13** : *265-286.*

Williamson, D.T and B. Mbano (1988). Wildebeest Mortality During 1983 at Lake Xau, Botswana. *Afr. J. Ecol.* **26** : 341-344.

Williamson, D.T., J. Williamson and K.T. Kgwamotsoki (1988). Wildebeest Migration in the Kalahari. *Afr. Journal of Ecology.* pp. 269-280.

Yonzon *et al.* (1991). Geographic Information System for assessing habitat and estimating population of red pandas in Langthang National Park, Nepal. *Ambio.* **20** (7) : 285-288.

Young, T.N., J.R. Elby, H.L. Allen, M.J. Hewitt and K.R. Dixon (1987). Wildlife Habitat Analysis Using Landsat and Radiotelemetry in GIS with Application to Spotted Owl Preference for Old Growth. *Proc. GIS'87,* San Francisco. American Society for Photogrammetry and Remote Sensing and American Congress on Surveying and Mapping. University of California. pp. 595-600.