Land Use, Forest Fragmentation and River Dynamics in Dudhwa Landscape and Their Conservation Implications

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by
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Certificate

This is to certify that the thesis of **Ms. Neha Midha** entitled **"Land Use, Forest Fragmentation, and River Dynamics in Dudhwa Landscape and Their Conservation Implications"** is an original piece of work submitted to the Saurashtra University, Rajkot (Gujarat), for the award of the **Doctor of Philosophy in Wildlife Science.**

Ms. Neha Midha has put in more than six terms of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted for any degree of any other University or Institution.

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Summary

Introduction: The natural areas (forests, grasslands, wetlands, coasts, and marine) recognized as repository of biodiversity continue to exploit, shrink, and deteriorate. This is attributed to the expanding human footprint, ever increasing biomass based demands, greed, and ignorance. Protected areas considered as a mean to conserve biodiversity were soon found to be inadequate in accomplishing conservation goals as majority they exist as habitat remnants within a human dominated matrix, mainly occupied by agriculture, settlement, developmental activities, and degraded areas. Under such circumstances, doubts have been raised about the integrity of natural ecosystems, persistence of ecological processes, and even protected areas themselves. Understanding the dynamics and heterogeneity of forested landscape becomes vital requirement for planning and management of forests when multiple objectives including the maintenance of biodiversity are being aimed. The 'Dudhwa landscape' is one of the forested landscapes which has been greatly influenced by 'disturbance', whether natural or human induced. The land use changes, forest fragmentation, and altered river dynamics represent the most direct effects of human on this globally important landscape and shown to have a cascade of impacts on its complex and dynamic nature.

The Aim: The present study aimed to assess land use, forest fragmentation and river dynamics in Dudhwa landscape and their effect on diversity, vegetation, and species of concern i.e. swamp deer (*Cervus duvauceli duvauceli*). Specific objectives addressed description of

landscape spatial patterns, and evaluation of efficacy of high resolution satellite data in the development of spatial database; quantification of forest fragmentation, and assessment of structure and composition of forest vegetation; and understanding channel planform, changes in Sharda River, construction of Locational Probability Model of a stretch of Sharda River, and implications for conservation of endangered swamp deer and its prime habitat i.e. Jhadi *taal* in Kisanpur Wildlife Sanctuary.

Study Area: The study focused on the 'Dudhwa landscape' which represents the part of *Terai* ecosystem in the foothills of the Himalaya. The Sal (*Shorea robusta*) dominated forests interspersed with tall grasslands and numerous swamps characterize this tract and once this dynamic woodland-grassland-wetland complex harboured a variety of floral and faunal life including several charismatic and obligate species. The landscape witnessed sea change, mainly during past 150 years or so on account of long history of forest management, settlement of migrants, changes in land use, agriculture expansion, and various developmental activities. As a result, today the landscape depicts three large forest fragments and several, small and scattered forest fragments amidst human dominated matrix. Three large forest fragments have been designated as protected areas and they are: Dudhwa National Park (DNP), Kishanpur Wildlife Sanctuary (KWS), and Katerniaghat Wildlife Sanctuary (KAT) while small fragments together constitute two managed forests *viz.,* North Kheri Forest Division (NKFD) and South Kheri Forest Division (SKFD). Besides several swamps, streams, and rivulets, Sharda and Ghagra are two prominent rivers of the landscape. Sharda River divides jurisdiction of two managed forests. The landscape is located between Lat N $27^0$40' and $28^0$43', and Long E $80^0$00' and $81^0$19' with the

Indo-Nepal international border constituting its northern boundary. The major portion of the landscape lies in Lakhimpur Kheri and Bahraich Districts of Uttar Pradesh while a smaller extent extends into adjacent districts i.e. Shajahanpur and Pilibhit. The landscape covered 8,093.3 sq km area. Owing to dominance of fertile floodplain, above districts experienced boom in human population and resultant agriculture expansion during the post-independence period of the country. Currently, more than 60% of the land is under plough in these districts.

The Approach: In view of the multi-facet study objectives and vast area, it was imperative to adopt a holistic approach so as to have an insight on land use, forest fragmentation, and vegetation in the constituent areas of the landscape, and also on the river dynamics, a major disturbance factor influencing the floodplain and swamp deer. The field studies were carried out during 2005 and 2006. A combination of well tested field assessment methods and modern techniques *viz.,* Remote Sensing and GIS were employed in the present study. High resolution data of IRS P-6 LISS IV of 2004-05 was used for the assessment of land use/land cover in three constituent areas (DNP, KWS, and KAT). The efficacy of high resolution data was ascertained by qualitative and quantitative comparison with two medium resolution data i.e. Landsat ETM^+ and IRS 1D LISS III. The qualitative comparison included the visual analysis of features while quantitative comparison involved estimation of extent of mapping in three data sets. The extent and magnitude of forest fragmentation in DNP and KAT were assessed based on seven class level metrics computed using FRAGSTATS software. Nested sample plots were laid in KAT for detailed vegetation assessment and standard methods on phytosociology were used. Sixty kilometer stretch of Sharda River, adjacent to KWS and NKFD was selected for the assessment of channel planform changes. Various channel characteristics *viz.,* morphology, bank line position, sinuousity, channel area, braiding intensity were assessed and compared temporarily over a period of 53 years (1977-2001) using Landsat MSS, Landsat TM, Landsat ETM^{+}, and IRS 1D LISS III. The effect of dynamics of Sharda River on its floodplain and the prime habitat (Jhadi *taal*) of swamp deer was assessed by studying channel characteristics, changes in floodplain vegetation, and development of a Locational Probability Model.

Land Use, Vegetation, Forest Fragmentation, and River Dynamics: The assessment on land use/land cover patterns in Dudhwa landscape revealed 21 land use/land cover classes representing 14 forest classes, 2 grassland classes, 3 wetland classes, and 2 other land use classes. In general, three constituent areas/PAs were represented by 70% woodland, 18% grassland, 7% wetlands, and 5% other land use. Sal dominated forests occupied nearly 45% area of forest land/three PAs while 18.7% area was covered by other forests (Tropical Semi-Evergreen Forest, Tropical Seasonal Swamp Forest, Mixed Deciduous Forest, *Terminalia alata* Forest, Khair and Sissoo forest, *Aegle* Forest, and Scrub). Nearly 7% area was under plantations of Teak or other species (e.g. *Eucalyptus, Dalbergia sissoo, Acacia catechu*). Two types of grassland i.e. the Upland and Lowland Grassland were delineated. They occurred in a ratio of 1:2.3. Wetlands included rivers, streams, swamps, and areas under sand bar. Among other land use, fallow land and habitation were deciphered. Notable differences in the extent of land use/land cover classes among three PAs were recorded and likely reasons of such differences were attributed. The study contributed baseline information on the dynamic woodland-grassland-wetland complex for three PAs. These three inter-related entities occurred in approximate ratio of 70:23:07. DNP harboured the maximum extent of Dense Sal Forests, while Open Sal Forests dominated in KAT and KWS. *Chandar* Sal Forests occurred only in KWS. Four types of Sal dominated forests predominated in DNP while Mixed Deciduous Forests dominated KAT. The area under Rivers was pronounced in KAT. The Fallow land and habitations were also in maximum extent in KAT. The occurrence of Open Sal Forests on peripheral areas of DNP and KAT indicated the enhanced effect of biotic pressure due to large interface with matrix.

The study amply established the capability of high resolution IRS P-6 LISS IV in land use mapping of protected areas as compared to two medium resolution datasets.

Study revealed plant diversity of KAT and compared with other forest fragments. Accordingly, plant diversity in KAT was represented by 142 species belonging to 56 families and 123 genera. Plant species in KAT were represented by 58 tree, 32 shrub, 30 herb, 15 grass, 2 sedges, and 5 fern species. Sal obtained highest IVI due to its highest value of dominance based on basal area while *Mallotus phillipensis* registered highest value of frequency of occurrence and density. Shrub *Tiliacora acuminata* and herb *Curculigo orchioides* were found to be dominant. *Cyrtococcum patens* and *Imperata cylindrica* were frequently found grass species. Sal had desired regeneration while its prominent co-associate *Terminalia alata* registered poor regeneration and recruitment. On the contrary, exotic Teak showed good regeneration and good recruitment. This revelation is major a cause of management concern.

The computation of seven class level metrics using FRAGSTATS facilitated an understanding on the extent and magnitude of forest fragmentation in DNP and KAT. Accordingly, forests in DNP were less fragmented and of better habitat quality than forests in KAT. However, patches of forests in DNP were found for apart from each other indicating greater isolation of similar habitat type. This revelation could be affecting connectivity among similar patches.

Sharda River exhibited pronounced changes during the assessment period (53 years: 1977-2001). It showed increased instability with its west bank line more unstable. Within 53 years, the period of 1990-99 was found most influential as notable alteration in river channel were documented. The increasing instability of Sharda River is threatening the prime habitat (Jhadi *taal*) of endangered swamp deer in KWS. The Locational Probability Model developed for the Sharda River channel in the present study supported the argument of threat to Jhadi *taal* by sudden inundation or choking of swamp by heavy siltation in the near future. The river also depicted enhanced flooding and silt deposit. The floodplain was found to be encroached and pronounced conversion of newly found abandoned areas to agriculture was noticed, thus, hampering succession to natural vegetation.

Conclusion: Undoubtedly, the Dudhwa landscape has been under severe biotic pressure. As a result, the forestland, rivers, floodplain, and matrix have significantly altered. Mounting pressure and rapid land use changes are being continued. Three large forest fragments as PAs are almost disjoint in human dominated matrix, except little connectivity through riparian areas. In spite, various unexpected events rapid changes as well as undesirable biotic pressure, the landscape still harbours three large valuable forest fragments those are home to representative diversity of *Terai* ecosystem. Collectively, they harbour much of the desired diversity of this once, vast natural area. Three fragments along with other small forest fragments are the remaining treasure of the unique woodland-grassland-wetland complex. Nevertheless, challenges in managing those large and small forest fragments in the midst of rapidly changing matrix are not only enormous but also unimaginable. This calls for greater care of the entire landscape through proper planning, monitoring, management, and also involvement of local communities and other stakeholders. The network of rivers, rivulets, streams and swamps and their ecological functions and economic benefit could not be ignored in the landscape for future viability and sustainability of the forested landscape and its important and integral ingredients.

Chapter 1

Introduction

1.1 Global Change and Conservation Implications

"Global change" typically conjures images of climate change, biodiversity loss, sea level rise, and the other biophysical changes. Biophysical changes prominently include conversion and fragmentation of natural habitats and altered river hydrology (Barber *et al.*, 2004). These global changes are driven by human socio-economic development during the 20th century.

The drivers of socio-economic change *viz.* human population and economic growth, trade and consumption, and poverty and inequality have significantly altered the composition of the Earth's land cover, with a significant net global change from natural habitats (e.g. forests, grasslands, wetlands) to agricultural, pastoral, urban, and other human land uses (Marston *et al.*, 1997; Tilman *et al.*, 2001, Tscharntke *et al.*, 2005).

Natural habitats or wilderness areas have been well recognized as repository of biodiversity and thus have priority for conservation. Worldwide losses of biodiversity have occurred at an unprecedented scale during the last decades and have become a major concern for resource managers and conservationists. Human activities including resource extraction, agricultural expansion, urban development, extension of transportation infrastructure, and other forms of habitat alteration have resulted into habitat loss and fragmentation that are complex and unique to particular sites and regions. Most recent researches view both the loss of habitat and breaking apart of habitat by fragmentation as the major causes for species decline and biodiversity loss. It is now well appreciated that biodiversity conservation will not work without protecting the just 5% remaining pristine and natural habitats, but also not without a recognition of the contribution of the 'rest' 95% of the landscape which is not devoted primarily to nature conservation (Lindenmayer and Franklin, 2002; Tscharntke *et al.*, 2005).

The natural areas of the world, particularly in developing countries continue to shrink and deteriorate. Losses in biological diversity are reported at an alarming rate and they are attributed to the expanding human footprint on natural ecosystems. There is a growing global effort to stem this loss. This has necessitated protection of the representative sites that have the capacity to retain their typical biological diversity in perpetuity (Meffe and Carroll, 1997; Temple and Cary, 2002). Protected area establishment and management has been a cornerstone of biodiversity conservation and this has been a major activity in recent decades. Protected areas have increased in number and extent and considerable resources have been invested for their establishment and improved management. Protected areas are connected to their surrounding through ecological, economic, and cultural relationships (Zube, 1995). However, it was soon realized that most protected areas, by themselves, are not large enough or continuous enough to serve as a sufficient reserve of biological diversity. In several instances, protected areas are like islands and they also face the non-compatible land use scenario which does not augur well with protected area management (Mathur and Sinha, 2008). Many protected areas exist as habitat remnants within a matrix of agricultural lands and degraded areas. Therefore, the integrity of ecosystems within these protected areas and the ecological processes that sustain them are threatened.

It is also now well understood that the long-term survival of a free ranging, large faunal population is related to the amount of suitable habitat within a diverse landscape. In contrast, the survival of small (e.g., threatened and endangered) population in restricted landscape can be dominated by stochastic events and the spatial arrangements of suitable habitat within those landscape (Hanski, 1998; Dunning *et al*., 2002). Population survival can be even more tenuous if the species suitable habitat is transient in nature. Further, ecological processes and distribution of different floral and faunal communities at a particular site are influenced and they are the result of both local dynamics and processes acting at the broader scale of the surrounding landscape. Thus, in a dynamic landscape, population persistence may depend on both the *current* and *future* availability of sufficient suitable habitat.

The ability of a species to disperse to a new suitable habitat becomes important when the landscape consists of a constantly shifting mosaic of habitat patches of varying suitability. The potential influences of the surrounding landscape include effects on community composition, habitat quality, metapopulation dynamics, and local population persistence.

1.2 Forested Landscape

Diverse forests worldwide provide numerous goods and services that humanity derives for its sustenance and livelihoods. These demands have grown multifold and will be in even greater demand in the future (Sayer and Maginnis, 2005). The world will have more people, higher consumption of natural resources, more disposable income and leisure and less land available for forests. The stewards of tomorrow's forests lands will have to get more products and services out of smaller area and they will have to deploy the best technology together with the skills of the political, economic, and social sciences.

Forest systems have always changed, but the nature and rate of change will be unprecedented in the coming decades. The traditional forestry has already paved a way for the new approaches to *sustainable forestry* or *sustainable forest management* or in other words, the management of forest ecosystems. The landscape management approach to forest planning and conservation is being tested and validated. Landscapes reflect the totality of physical, ecological, and geographical entities, integrating all natural and human induced patterns and processes (Naveh, 1987). Landscapes are not merely structurally unique in composition, function, and spatial pattern, but they are also dynamic.

Heterogeneity is an inherent character of every landscape. According to Forman (1995), heterogeneity may be defined as the uneven, non random distribution of objects and the analysis of this pattern is of fundamental importance to understanding most ecological processes and the functioning of complicated systems such as landscapes. Heterogeneity and diversity have been recognized as two related concepts. Diversity describes the different quantity of the patches while heterogeneity represents the spatial complexity of the mosaic (Farina, 1998). Forest landscapes are rich in spatial heterogeneity from a variety of causes, including the environment, biotic interactions, disturbance, and succession (Spies and Turner, 1999). Spatial patterns can have a strong influence on population dynamics and ecosystem processes including the spread of disturbance. Biotic activities have had profound effects on the structure and composition of forests in a landscape and they influence the distribution, abundance, and dynamics of different species (Morris, 1987; Weins, 1986; Andren *et al.*, 1997; Tomar, 1998; Kumar *et al.*, 2002).

1.3 Forest Dynamics

Understanding the dynamics and heterogeneity of natural forest landscape is vital as management objectives for forests increasingly emphasize the maintenance of biological diversity. Despite enormous significance of forests to human society, forests are lost and fragmented worldwide. Forests represent dynamic mosaics created by disturbance, biotic processes, and succession. Thus, forest structure, composition, and ecological processes change over vast range of spatial and temporal scales. The condition of vegetation in a stand, landscape, or region is product of the interplay of forces of the disturbances and biotic development on a stage set by pattern and dynamics of climate, soil, and landform (Hunter, 1999).

Pickett and White (1985) have defined disturbance as ‘any relatively discrete event in time that disrupts ecosystem, community, or population structure and change resources, substrate availability, or the physical environment’. Important natural disturbance agents include fire, wind, herbivore outbreaks as well as floods, avalanches, ice storm, landslides, volcanic eruptions, and glaciers (Oliver and Larson, 1996) while anthropogenic or human induced disturbances include clearcutting; road building; flood control; fire control; forest clearing for agriculture and development; application of fertilizers; and indirect effects of non-forest activities on climate and atmosphere. Physical attributes of disturbance include type, magnitude, and intensity, timing and spatial distribution (Pickett and White, 1985; Spies and Turner, 1999).

Spies and Turner (1999) have described that the alteration of landscape disturbance regimes by humans has had following four major effects:

(a) *Exclusion of fire from fire-dependent ecosystem*: Human alteration of fire regimes has had profound effects on the structure and function of many forest ecosystems. In some cases, human activity has increased fire frequency and intensity causing losses in species diversity and ecosystem productivity. On the other hand, suppression of fire by humans has drastically changed successional pathways, forest composition and structure, and increased the incidence of disease and insect outbreak in many forest ecosystems. The implications to managers are clear: if you change the fire regime you change the ecosystem and the landscape.

(b) *Reduction in structural and compositional diversity through intensive forest management*: Intensive forest management for timber and wood fibre production has altered disturbance regime by increasing the frequency and severity of disturbances in many landscapes relative to natural and semi-natural disturbance regimes. In addition it results in dissection from roads and perforation and fragmentation of remaining forest patches, thereby increasing forest edges.

(c) *Conversion of forests to other land cover types such as agriculture and development*: It has enormous impact on the loss of forest biodiversity throughout history. The conversion from forest management to intensive agriculture results in drastic semi-permanent changes at stands and landscape levels. Landscape effects include rapid and severe forest fragmentation. The message to management is that restoration of forests from loss and severe disturbances in agricultural landscapes is possible even where forests have been removed and soils altered, but it will be slow process and will probably not return to the same structure and composition that occurred before disturbance.

(d) *Alteration of hydrological processes and disturbance regime*: Human effects on the hydrology of rivers and wetlands are another example where humans have altered the frequency and severity of disturbance regimes causing decline in some species and changes in community structure. Channelization and damming of rivers have often resulted in fewer floods and narrower, less complex river channels and floodplains. The effects of altered flow and meandering rate can reduce the abundance of early successional species reducing species diversity and habitat complexity. The message to management is that floods are critical disturbances in maintaining the diversity and function of riparian forests.

Forested landscapes are dynamic – they are always in transition and have always been in a state of constant change. Though the rates and agents of change vary temporally and spatially, change underlines the natural state of world's forests. Land-use patterns and disturbance regimes are two of the dynamic agents that can have profound effects on the abundance, distribution, and diversity of terrestrial vertebrates. The need for conservation and management of forest and wildlife resources requires human to influence the uses of land and the sizes and distributions of wildlife populations to maintain specific habitat conditions. Identification of the primary agents of change and their extent and magnitude are necessary to maintain forested ecosystems and their faunal components. An understanding of the back-ground rates and causes of change in forested landscape can help to guide conservation efforts on many scales.

As stated above, there are many natural and human induced disturbances in forested landscapes and depending upon their magnitude, intensity, timing, and spatial distribution, they influence various ecological processes and spatial patterns. Such three prominent processes/patterns are described below:

1.3.1 Land Use/Land Cover

Land is most precious resource, vital for the well-being and sustenance of the people (Singh, 1997). Human communities often depend on the nature specially the immediate environment for satisfaction of their requirement, basic needs, and livelihoods. The “Land Use” is defined as the way in which and the purpose for which human beings employ the land and its resources. Land Cover is altered principally by direct human use through agriculture, pasture, forestry, and development. Three major proximate causes of land use change are economic exploitation of natural resources (logging, mining, hydroelectric power, etc), population expansion (urbanization and colonization), and the expansion of agriculture (permanent agriculture and shifting cultivation).

Land use patterns affect both terrestrial and aquatic systems and influence biodiversity for several reasons (Reiners *et al*., 1994; Cooper, 1995; Pearson, 2002). Changes in land use may alter the relative abundance of natural habitats and result in the establishment of new land cover types. Species richness may be enhanced by the addition of new cover types, but natural habitat are often reduced, leaving less area available for native species (Walker, 1992). Exotic species may also become established and out compete the native biota. Spatial pattern of habitat is likely to be altered due to change in land use, often resulting in fragmentation of once contiguous habitat. Projecting patterns of species presence and abundance in changing landscape remains a key challenge in sustaining biodiversity and clearly, the conservation of native species and their habitat involves a landscape-level approach (Franklin, 1993 and 1994; Tracy and Brussard, 1994; Pearson, 2002).

Spatial distribution of land use/land cover information and its changes is desirable for any planning, management and monitoring programmes at local, regional, and national levels. This information not only provides a better understanding of land utilization aspects but also plays a vital role in the formulation of policies and programmes required for conservation and development (Srivastava and Gupta, 2003).

1.3.2 Forest Fragmentation

Forest fragmentation occurs when a large area of native forest is transformed into a series of smaller remnant patches isolated by an intervening matrix hostile to forest organisms (Didham, 1997; Laurance and Bierregaard Jr, 1997; Haila, 1999). The resulting configuration often resembles an ‘archipelago’ in which forest ‘island’ are surrounded by a ‘sea’ of another type of environment. The most important factor driving forest fragmentation, by far, has been agriculture. The forest fragmentation result into: (i) loss of original habitat, (ii) reduction in remnant patch size, (iii) increasing isolation of remnant patches, and (iv) exposure of forest fragments to edge effects as a result of the abrupt transition between forest and matrix habitat (Andren, 1994; Murcia, 1995; Didham, 1997). Fragmentation is one of the most severe processes to depress biodiversity (Farina, 1998). The harmful consequences that follow from fragmentation have been amply documented in ecological literature. They usually focus on above stated four aspects of fragmentation (Laurance and Bierregaard Jr, 1997; Hunter, 1999; Haila, 1999). Several papers have recently focused on the fragmentation process as a central issue in landscape ecology and conservation planning (e.g. Wilcove *et al.*, 1986; Saunders *et al.*, 1991).

Fragmentation has a negative effect on many species of plants and animals, and on ecological processes. However, habitat fragmentation is species specific, so an environment perceived as fragmented by one species can be perceived as homogeneous by another. Fragmentation increases habitat edges, and edge-sensitive species (forest interior species) can reduce in abundance and large predators for instance, disappear, producing outbreak of forages such as deer (Farina, 1998). Fragmentation, therefore, reduces specialist habitat-demanding species while favours generalists.

The concept of forest fragmentation needs to understand more rigorously as most researchers measure fragmentation in ways that do not distinguish between forest *loss* and forest *fragmentation* per se (Haila, 1999; Fahrig, 2003). These processes belong together. Fragmentation can be considered as continuum process, according to a landscape perspective, matrix and patches are the elements that have to be used when considering a landscape, fragmented or not. Forest fragmentation refers to a change in spatial configuration of forests so that formerly continuous forest areas turn into small stands isolated from other stands by intensively modified lands such as crop lands, pastures, clear cuts, and silvicultural plantations. The crux of the matter is disruption of continuity. Forest loss is also expected to induce changes in the flora and fauna. This occurs for two reasons: firstly, a reduction in forest area or reduction in the total amount of resources available for forest organisms, and secondly, as no forest is internally homogeneous, a reduction in forest area also results in a decrease in the range of environments available within the forest. Fahrig (2003) thus in its review article on effects of fragmentation on biodiversity strongly suggests that the term 'fragmentation' should be limited to the breaking apart of forest/habitat of a species. Actual forest/habitat loss should be called forest/habitat loss; it has important effects on biodiversity that are independent of any effects of forest/habitat fragmentation per se. Forest/habitat fragmentation should be reserved for changes in habitat configuration that result from the breaking apart of habitat, independent of forest/ habitat loss.

1.3.3 River Dynamics and Floodplain Ecosystem

Riverine networks are large-scale networks of streams and rivers that occur in all forested regions. Streams and rivers are broadly differentiated on the basis of "volumes of water moving within a visible channel, plus subsurface water moving in the same direction and the associated floodplain and riparian vegetation" (Naiman and Bilby, 1998). Vegetation associated with streams and rivers is variously described as a riparian or streamside influence zone. River systems are among the most fragmented and regulated portions of the landscape of many countries. For example, 70% of the total water discharge of 139 of the world's largest river systems is affected by reservoir operation, interbasin transfer, and irrigation. This means that the interrelationships between the river channel and the floodplain may be totally interrupted in many cases because of the regulation of discharge, either through withdrawals or from reservoir storage (Brinson and Verhoeven, 1999). Some of the most common alterations to riparian forests are stream channelization, channel constriction, and the upstream and downstream effects of altered flows due to impoundments and diversions. All affect the fundamental character of the riparian forest by altering water delivery and geomorphology.

Rivers are complex wetlands that not only include the bed, banks, and water of the watercourse, but also the associated ground waters and the floodplain related wetlands. From their source to their mouth and up to a considerable distance out to the sea, rivers encompass a sequence of different ecosystem types. The conservation or restoration of biodiversity along a river depends on the maintenance of essential ecological processes, such as periodic floods, minimum water flows, and specific rates of sediment transport. These processes are often influenced by activities upstream that can have far reaching consequences on the state of downstream ecosystem (Shine and de Klemm, 1999; Hussain, 2001).

Biodiversity patterns are directly and indirectly influenced by the geomorphology of riverine landscape. The term riverine landscape implies a holistic geomorphic perspective of the extensive interconnected series of biotopes and environmental gradients that, with their biotic communities, constitute fluvial systems. Natural disturbance regimes maintain multiple interactive pathways (connectivity) across the riverine landscape. Disturbance and environmental gradients, acting in concert, result in a positive feedback between connectivity and spatio-temporal heterogeneity that leads to the broad-scale patterns and processes responsible for high levels of biodiversity (Ward, 1998; Ward *et al*., 2002).

A floodplain is an accumulation of deposits carried and then set down by flowing water. Water is hence the dynamic components of the alluvial landscape that distributes energy, material, and information across and through the plain. Water quantity and flow are important factors of floodplain or associated freshwater ecosystem health (Barber *et al.*, 2004). Fluxes of water, sediments, and energy are both longitudinal (from upstream to downstream) and transversal (from the river to the edges of the plain and *vice versa*). Water movements are also vertical, with infiltration within the sediments of the plain and circulation through them (Amoros and Petts, 1993; Schnitzler, 1997). In alluvial plains, river dynamics is recognized as the major force for landscape patterning and ecosystem distribution (Schnitzler, 1997).

Understanding the planform (spatial arrangement of channels in the landscape) dynamics of river channels has important implication for maintaining biodiversity (Naiman *et al*., 1993; Hughes, 1997, Ward *et al*., 1999). Investigation of historical channel change provides insight into how stream channels respond to flood events. With this information, land and resource managers are able to make decisions that minimize the social costs (e.g., flood damage to property) and maximize the ecological benefits of flooding (e.g., rehabilitating riparian vegetation and deterring the proliferation of exotic species).

In India, once vast expanse of natural forests all along the foothills of Himalayas or the '*Terai*' region have been severely impacted by human induced disturbances *viz.* long history of forest management, conversion of forests for agriculture expansion, and other developmental works. 'Dudhwa landscape' is one such site representing this vast expanse of *Terai* region.

1.4 Dudhwa Landscape

'Dudhwa landscape' lies in the foothills of the Himalayas and represents the dynamic Indian *Terai* ecosystem. This region is a vast flat alluvial floodplain and is drained by several tributaries of river Ganga. The forest is mainly moist deciduous, dominated by the most valuable Sal (*Shorea robusta*) forests of

India. A significant attribute of *Terai* is Sal forest interspersed with tall wet grasslands and swamps. The high water table, annual flooding, and synergistic influences of prescribed grassland burning are primary factors defining the characteristics of this tract. The resulting woodland-grassland-wetland complex harbours a variety of floral and faunal life including several charismatic and obligate species (Kumar *et al.*, 2002).

Forest reserves were first carved out in early 1880s and they were subjected to extensive forest working based on silvicultural prescriptions. Forest working included extensive clear felling and raising of monoculture plantations. This also required development of a rail and road network in the area. Dudhwa landscape has undergone several transformations since the turn of 20th century. The Dudhwa landscape witnessed a sea change during the country's post independence era as a result of abrupt changes in land use policy, settlement of refugees, uncontrolled expansion of agriculture and the associated large scale reclamation/conversion of grassland and swamp habitats. The landscape was further influenced in 1960s by heavy deforestation on its north-western side in the adjacent international region of Nepal. This was followed by channelization of rivers on the upper reaches and altering natural flow regimes. Intensive land use changes and other developmental activities have greatly reduced once extensive wilderness into smaller fragments of natural forests. Today, Dudhwa landscape harbours several small scattered as well as a few, large forest fragments amidst human and agriculture dominated matrix. Agriculture is now the mainstay of the local economy instead of traditional forest based economy. Remnant forest patches are surrounded by villages dominated by agrarian human population. The intricate complex of diverse forests, agriculture and village system is being continuously affected by changing course of major rivers in the area and resultant enhanced river dynamics.

Nevertheless, the Government of Uttar Pradesh was always alive to concerns of decline of highly endangered species i.e. Northern swamp deer or Barasingha (*Cervus duvauceli duvauceli*) and other issues of wildlife conservation in the region and from time to time established wildlife protected areas and upgraded their legal status. At present, the ‘Dudhwa landscape’ embraces three protected areas (PAs) - Dudhwa National Park (DNP), Kishanpur Wildlife Sanctuary (KWS), and Katerniaghat Wildlife Sanctuary (KAT) carved out from relatively larger forest fragments and they form part of Dudhwa Tiger Reserve. It is the only notified Tiger Reserve in the most populated and fifth largest state of India i.e. Uttar Pradesh. The Reserve represents the last and best protected remnants of *Terai* ecosystem.

Despite large scale transformation, Dudhwa landscape remains a vital element of global and regional biodiversity but current and future challenges for management are great. Past interventions that focused on social and economic uses are pervasive and have set forests, grasslands, wetlands, and overall landscape on a trajectory of change with poorly understood implications for biodiversity. Besides long history of forest management, changes in land use, forest fragmentation, and river dynamics are being considered as most important drivers or themes for understanding the complex and dynamic Dudhwa landscape.

Several research studies relevant to the Indian *Terai* and Dudhwa landscape exist (Mathur, 2000; Kumar *et al.*, 2002) and they have significantly contributed on different aspects of physical, biological, ecological, socio-economic and management. A review of literature is being provided in the next chapter. However, it is amply clear that the *Terai* region and the Dudhwa landscape will continue to experience rapid change and development resulting into loss of forest extent and its quality, forest fragmentation, and enhanced floodplain dynamics. The challenges arising due to such changes and associated processes will further aggravate the situation and jeopardise the fate of already rare and threatened floral and faunal species of the area.

1.5 Future Direction

Forest conservation and management in the present era face new challenges and greater uncertainty. The numerous goods and services that humanity derives from forests will be in even greater demand in future (Sayer and

Maginnis, 2005). It has been well realized that the two main themes: ‘preservation of endangered species’ and ‘establishment of biological reserves’ of conservation efforts in past decades are inadequate to achieve conservation goals (Brown *et al.*, 2003). Further, more than 90 per cent of the world’s forests are in matrix outside reserve systems. The ‘matrix’ comprises landscape areas that are not designated primarily for conservation of natural ecosystems, ecological processes, and biodiversity regardless of their current conditions (whether natural or developed). In the parlance of landscape ecology, the matrix has been defined as the dominant and most extensive ‘patch type’ (Forman, 1995; Crow and Gustafson**,** 1997; Lindermayer and Franklin, 2002). Brown *et al*. (2003) estimated that the semi-natural matrix comprises more than 85% of the land area worldwide, with approximately 11% of the world’s land devoted to agriculture.

The term ‘matrix management’ includes approaches to conserve biodiversity outside reserve systems. The conservation of biodiversity is only one of several possible goals of matrix management. Other goals are production of commodities e.g. wood and services such as well regulated flows of high quality water. The condition of the matrix and management practices inside it will determine whether different goals and services can be sustained or not. Matrix is expected to play four critical roles for conservation of biodiversity. These are: (a) supporting populations of species, (b) regulating the dispersal and movement of organisms, (c) buffering sensitive areas and reserves, and (d) maintaining the aquatic systems (Lindenmayer and Franklin, 2002; Mathur and Sinha, 2008).

Conditions in the matrix are pivotal to studies of habitat fragmentation, metapopulation dynamics, population viability, extinction proneness, edge effects and reserve designs. The response of biota in habitat fragments are not isolated from conditions in the surrounding matrix. Thus, Lindenmayer and Franklin (2002) and Bradshaw and Marquet (2003) advocate that it is important to shift the emphasis from the fragments to the managemnt of matrix in which they are embedded. If the biota in the fragmented landscape is to persist then the management of the matrix becomes all important.

Ameliorating the matrix may be the most important way to manage fragments (Crome, 1994). Recognising the importance of both large ecological reserves as well as appropriate management of matrix lands for forest biodiversity calls for a comprehensive landscape approach to conservation. A landscape perspective fosters multi-scale, cross-boundary, adaptive, and integrated approaches (Liu and Taylor, 2002)

The importance of information base developed through rigorous research and monitoring activities for the management of ecological reserves and endangered species has been emphatically highlighted in the voluminous literature for quite sometime (MacKinnon *et al*., 1986; Barber *et al*., 2004). Several authors have revealed important gaps in the required information (Hunter, 1999; Laurance and Bierregards, 1997). Since most of the priority conservation landscapes worldwide are being modified by human action at an unprecedented pace, it is now more pertinent to have required information on matrix lands and strengthen such information from the new data periodically. It can not be over-emphasized that 'better science' is essential for sound decision making (Reid, 2002).

Landscape-level planning and management for biodiversity conservation have been hindered by lack of comprehensive compatible, high quality information about the ecological resources (Campa III *et al*., 1999). For natural resource managers to be effective across diverse and dynamic landscape, they will require more complex data sets. Obtaining these data will sometimes require innovative approaches that integrate methods from different scientific disciplines, such as landscape ecology and molecular genetics. Use of the compatible, user friendly GIS technology will allow managers to use these data sets to develop a spatial database in GIS domain. Managers are also required to integrate GIS technology with global positioning system and remote sensing. Tools for data analysis and integration include GIS, spatial statistics, and modelling. GIS systems are arguably the most important tool for storing, manipulating, analysing, and integrating both spatial and non-spatial data. Research methods in landscape ecology have progressed remarkably fast over the last 2-3 decades (Turner and Gardner, 1991; Farina, 2000; Liu and Taylor, 2002). According to Forman (1995) one of the 12 principles of landscape ecology states that spatial arrangement of patches is a major determinant of functional movement across the landscape. A new generation of satellites with improved temporal frequency of data acquisition, better spatial, spectral resolution has considerably enhanced the potential of remote sensing in development of spatial information. Improved spatial resolution data allows identification and assessment of important smaller patches and textural features on ground (Mahito and Takeshi, 1998; O'Hara, 2002). Investigations into how new scientific findings are used by multiple stakeholders those are using the landscape are also critical for the effective management on the ground.

1.6 Research Questions, Aim, Hypotheses, and Objectives

Three large constituent reserves in the Dudhwa landscape on one hand pose several pertinent research questions in the mind of scientists, managers, and conservationists. Firstly, on account of a long history of forest management (silvicultural operations, clear felling, plantations, creation of road and rail infrastructure, and other resource extraction activities) for almost a century (1880s to 1970s) and secondly, 'passive management' during past three decades or so due to curb on forestry operations and resultant reduced extraction. On other hand, the vast matrix witnessed a sea change during the post-independence era of the country mainly owing to expansion of agriculture and continues to experience large scale land use changes due to rapid development.

1.6.1 Research Questions

Keeping in view the above description, following pertinent questions are posed in the context of Dudhwa landscape:

- How past forest management in three constituent ecological reserves has changed forest structure and composition?

- What is the impact of past forestry practices on floral and faunal species of concern?

- How past social and economic uses have set forest and grassland ecosystems on a trajectory of change and their implications on the structure and composition of forest and grassland habitats?

- What are the land use changes and how they have influenced spatial and temporal patterns of the landscape (ecological reserves and matrix)?

- What is the extent and rate of forest fragmentation due to land use changes and other developmental activities?

- What are the patterns of river dynamics and how they influence the floodplain ecosystem?

- How much flood (amount, frequency, intensity, and duration) is vital for maintaining the representative biodiversity?

- What is the nature and extent of human-wildlife conflict arising due to disjunct forest fragments and isolated animal populations?

- What is the available connectivity between larger constituent reserves and its effectiveness?

- How faunal species of concern will respond in future to current practices of matrix management; predict over-all conservation scenario, and plan for appropriate management interventions?

1.6.2 The Aim, Hypotheses, and Objectives

The present study aimed to study the effect of land use, forest fragmentation, and river dynamics in Dudhwa landscape on conservation of biodiversity.

Specifically, the study intended to test the following hypotheses:

- ♦ Over a period of time, interplay of forces of disturbance and biotic development has not affected spatial and temporal patterns of landscape diversity and forest vegetation.

- ♦ Active river migration and flooding enhance diversity of floodplain.

In order to accomplish above goals, address various questions, and hypotheses, the following objectives were set forth for the present study:

- To assess landscape spatial patterns.

- To assess the efficacy of high resolution data in the development of a spatial database.

- To assess the structure and composition of forest vegetation.

- To quantify the extent of forest fragmentation.

- To assess river dynamics and its implications on species of concern.

1.7 Organization of the Thesis

The thesis contains eight chapters. Out of this, three Chapters (1, 2, and 8) are general in nature as they present Introduction, Study Area, and General Discussion and Conclusion, respectively. Rest five Chapters (3 to 7) are theme based and address study objectives. Hence, each of these Chapters focus on a specific theme, provide brief review of literature, methodology used, results, and discussion. The Chapter 1 deals with the general introduction describing global changes and their conservation implications. The major portion of this Chapter dwells with the subject of dynamics of forested landscapes. It highlights drivers of such dynamics i.e. disturbance regimes and their effects. Chapter briefly draw attention to a highly complex and dynamic forested landscape i.e. ‘Dudhwa landscape’ in *Terai* region of India which has experienced rapid land use changes besides long history of forest management. These changes and time to time extreme management interventions have resulted into far reaching implications for the conservation of representative biodiversity. Chapter also pose pertinent research questions to be addressed, hypotheses to be tested, aim, and objectives of the present study. The Chapter 2 deals with the study area and highlights its uniqueness, conservation significance, and pronounced socio-economic changes. Chapter also presents a review of literature. The Chapter 3 presents an assessment on the application of high resolution data in development of a spatial database and describes spatial patterns in the landscape. The Chapter 4 describes the structure and composition of forest vegetation and discusses the impact of past management. The Chapter 5 deals with an assessment of forest fragmentation and its impact on landscape patterns. The Chapter 6 pertains to the most significant disturbance regime i.e. the river dynamics and describes its importance for the maintenance of ecological integrity of Dudhwa landscape. This is followed by Chapter 7 which presents impact of altered river dynamics on floodplain ecosystem, particularly conservation of an endangered and featured faunal species i.e. swamp deer. The Chapter 8 attempts to integrate understanding of various disturbance regimes influencing the dynamic landscape covered under Chapter 3 to 7 and their implications for conservation. The Chapter concluded the study by presenting future directions for the sustainability of a globally and nationally significant landscape. The Chapter 8 is followed by a list of references.

Chapter 2

Study Area

2.1 *Terai* – A Global Priority Ecoregion

The *Terai* ("moist land") is a narrow belt of marshy grasslands, savannas, and forests at the base of the Himalaya range in India, Nepal, and Bhutan, from the Yamuna River in the west to the Brahmaputra River in the east. Above the *Terai* belt lies the Bhabhar, a forested belt of rock, gravel, and soil eroded from the Himalayas, where the water table lies from 5 to 37 m deep. The *Terai* zone lies below the Bhabhar, and is composed of alternate layers of clay and sand, with a high water table that creates many springs and wetlands. The *Terai* zone is inundated annually by the monsoon-swollen rivers of the Himalaya. Below lies the great alluvial plain of the Yamuna, Ganga, Brahmaputra, and their tributaries.

High water table, annual flooding, and the synergistic influence of deliberate annual grassland fires characterize the *Terai* tract (Mathur, 2000). Once *Terai* represented vast expanse of wilderness or a lush belt of green vegetation comprising mainly moist deciduous forests dominated by valuable Sal (*Shorea robusta*) interspersed with tall grasslands and numerous swamps. The tall grasslands mainly dominated by *Saccharum*, *Narenga*, *Sclerostachya*, *Imperata*, and *Typha* species. Occasionally, grass height exceeds 6 m. Unique complex of woodland-grassland-wetland ecosystem once harboured a variety of floral and faunal life, including several charismatic and obligate species *viz.* tiger (*Panthera tigris*), Asian elephant (*Elephas maximum*), great one-horned rhinoceros (*Rhinoceros unicornis*), Asian wild buffalo (*Bubalus bubalis*), swamp deer or barasingha (*Cervus duvauceli duvauceli*), hispid hare (*Caprolagus hispidus*), bengal florican (*Hubraopsis bengalensis*) and pygmy hog (*Sus salvanicus*).

For a considerable time the *Terai* region was inhospitable due to extensive wilderness, flooding, and its characteristic of a disease (e.g. malaria and influenza) prone area. The area remained thinly populated for a long time, except by local tribes (*Tharus*). The area started getting attention with the arrival of Britishers. Reserved forests were carved out and forests were worked for the production forestry and extraction of timber. Rail and road network was established to facilitate the transportation of Sal sleepers for the development of rail infrastructure within the country. Heavy demands of wood for the World War I and II put an extra pressure on the forests of *Terai*. Forests were clearfelled and extensive monoculture plantations of exotic species were raised. Changes in land use policy, settlement of refugees, heavy deforestation to meet growing timber demand, large-scale reclamation of swamps and grasslands for rapid expansion of agriculture, and other developmental activities during the country's post independence era, resulted into the transformation of this once great wilderness to immense expanse of human and agriculture dominated landscape. Ever increasing demand of forest resources by massive rural populations and other factors like unregulated livestock grazing, fire, and enhanced flooding further greatly reduced the extensive contiguous forests of *Terai* into smaller fragments. Past few decades also witnessed local extinctions and population declines of some faunal species.

Appreciating the outstanding conservation significance of remnant forests interspersed with grasslands and swamps those still contain exceptional concentration of species and endemics, the *Terai* region was included in the list of 200 Ecoregions which are part of a global strategy to conserve biodiversity aiming to protect representative examples of all of the world's ecosystems (Olson and Dinerstein, 1998 and 2002; Orians, 1993; Groves *et al.*, 2000; Wikramanayake *et al.*, 2001). Ecoregion in the present context (*Terai*) has been designated as the "Terai-Duar Savannas and Grasslands." According to the biogeographic classification by Rodgers *et al.* (2002), the *Terai* region represents two distinct biogeographic zones and three biotic provinces: 7-Gangetic Plain (7A – Upper Gangetic Plain and 7B-Lower Gangetic Plain), and 9-North-East India (9A – Brahmaputra Valley). Rodgers and Panwar (1988) also pointed out that the Gangetic Plain is topographically homogeneous for hundreds of kilometres and one of the most fertile areas in the world and supports a dense and still growing human population. In addition, the study raised the concern that much of the original vegetation has been converted into cropland and natural vegetation is extremely rare and in very small patches. However, the Brahmaputra valley of North-East India still harbours relatively much larger areas of natural vegetation – swamps, grasslands, and fringing woodlands and forests. It is only here that the full richness of the large herbivore fauna typical of alluvial grasslands can still be seen: elephant, rhinoceros, buffalo, swamp deer, hog deer, pygmy hog, and hispid hare and further added that this valley system also forms an important migratory fly-way for wintering waterfowl.

Despite the national and global significance, much of the existing biodiversity in *Terai* lies outside protected areas (Mathur, 2000). The Indian *Terai* presently has 11 national parks and 47 wildlife sanctuaries covering altogether 10,659 sq km area. The protected area coverage represents just 2.5% geographical area of the Gangetic Plain biogeographic zone and Brahmaputra valley biotic province in North-East India. The average size computed for 58 PAs in the Indian *Terai* comes to 183.7 sq km against the country's overall average size computed to 267.4 sq km for 578 PAs. Astoundingly, the third largest biogeographic zone (Gangetic Plain) and Brahmaputra valley biotic province having luxuriant vegetation (forest, grassland, and swamps) till recent living memory is now have only three relatively large (400-850 sq km) protected areas. They are Dudhwa National Park, Uttar Pradesh in Upper Gangetic Plain; Valmiki National Park and Wildlife Sanctuary, Bihar in Lower Gangetic Plain; and Kaziranga National Park, Assam in the Brahmaputra Valley biotic province. Dudhwa National Park along with two other nearby notable PAs i.e. Kishanpur Wildlife Sanctuary and Katernaighat Wildlife Sanctuary acquire greater significance for conservation as a typical representative area of the Upper Gangetic Plain. These three PAs together constitute the only and famous Dudhwa Tiger Reserve in the state of Uttar Pradesh.

2.2 Study Area – Location, Constitution, and Extent

The study area – ‘Dudhwa landscape’ stretches mainly across two districts: Lakhimpur- Kheri and Bahraich of state Uttar Pradesh, India. A smaller extent also falls in adjacent districts of Shahjahanpur and Pilibhit (Fig. 2.1). The entire study area lies between latitide N 27˚40' and 28˚43' and longitude E 80˚00' and 81˚19' with Indo-Nepal International border constituting its northern boundry (Fig. 2.2). The landscape covers an area of 8093.3 sq km and includes mainly three larger forest fragments and several smaller scattered forest fragments amidst in the matrix dominated by agriculture. Larger fragments are Dudhwa National Park (DNP), Kishanpur Wildlife Sanctuary (KWS), and Katernaighat Wildlife Sanctuary (KAT) and they are legally notified protected areas under the Wildlife (Protection) Act, 1972 (MoEF, 1972) and smaller fragments constitute two managed forests i.e. North Kheri Forest Division (NKFD), and South Kheri Forest Division (SKFD).

The DNP is located in the district of Lakhimpur-Kheri (Kheri). It is located on its northern side and shares north-eastern boundry with Nepal which is defined to a large extent by Mohana River (Fig. 2.3). DNP covers an area of 490.3 sq km. Adjacent managed forest (reserved forest) of 190.0 sq km serves as its buffer (Table 2.1). Both the park and buffer were once part of North Kheri Forest Division, they were carved out and DNP was declared as National Park in 1977 (De, 2001).

Another river Sharda divides the forests of Kheri district into North Kheri Forest Division and South Kheri Forest Division. KWS was carved out from SKFD in 1972 and lies south of Sharda River (Fig. 2.2). The two PAs (DNP and KWS) are independent large blocks, lying about 15 km apart on either side of Sharda River. The intervening land is largely rural and with vast stretches of agriculture. A small western part of the Sanctuary lies in Shahjahanpur district and in total KWS covers an area of 203.4 sq km.

Fig. 2.1 – Dudhwa Landscape with Adjacent Districts in Uttar Pradesh, India

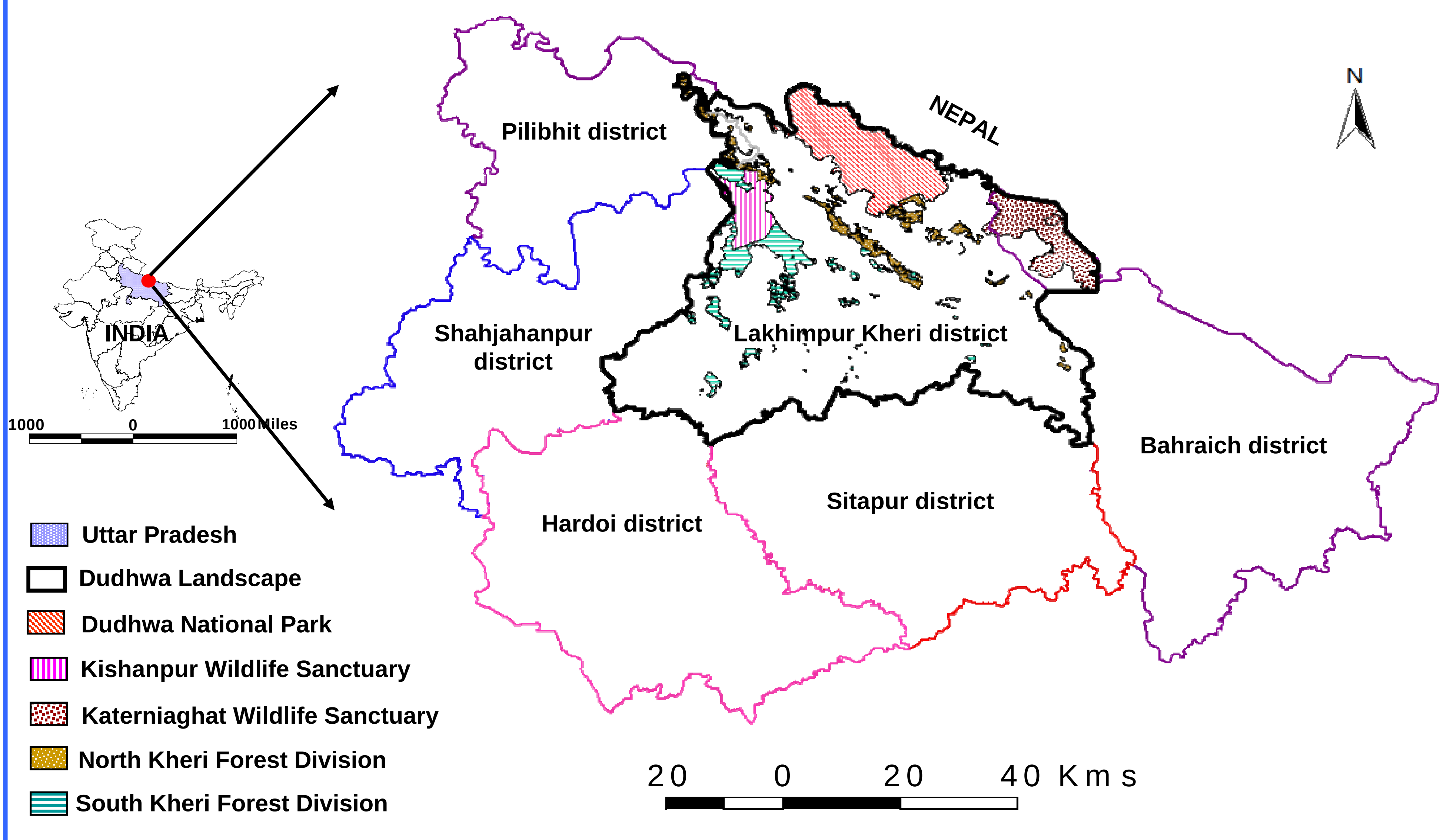


Fig. 2.2 – Dudhwa Landscape with Constituents Areas and Prominent Locations

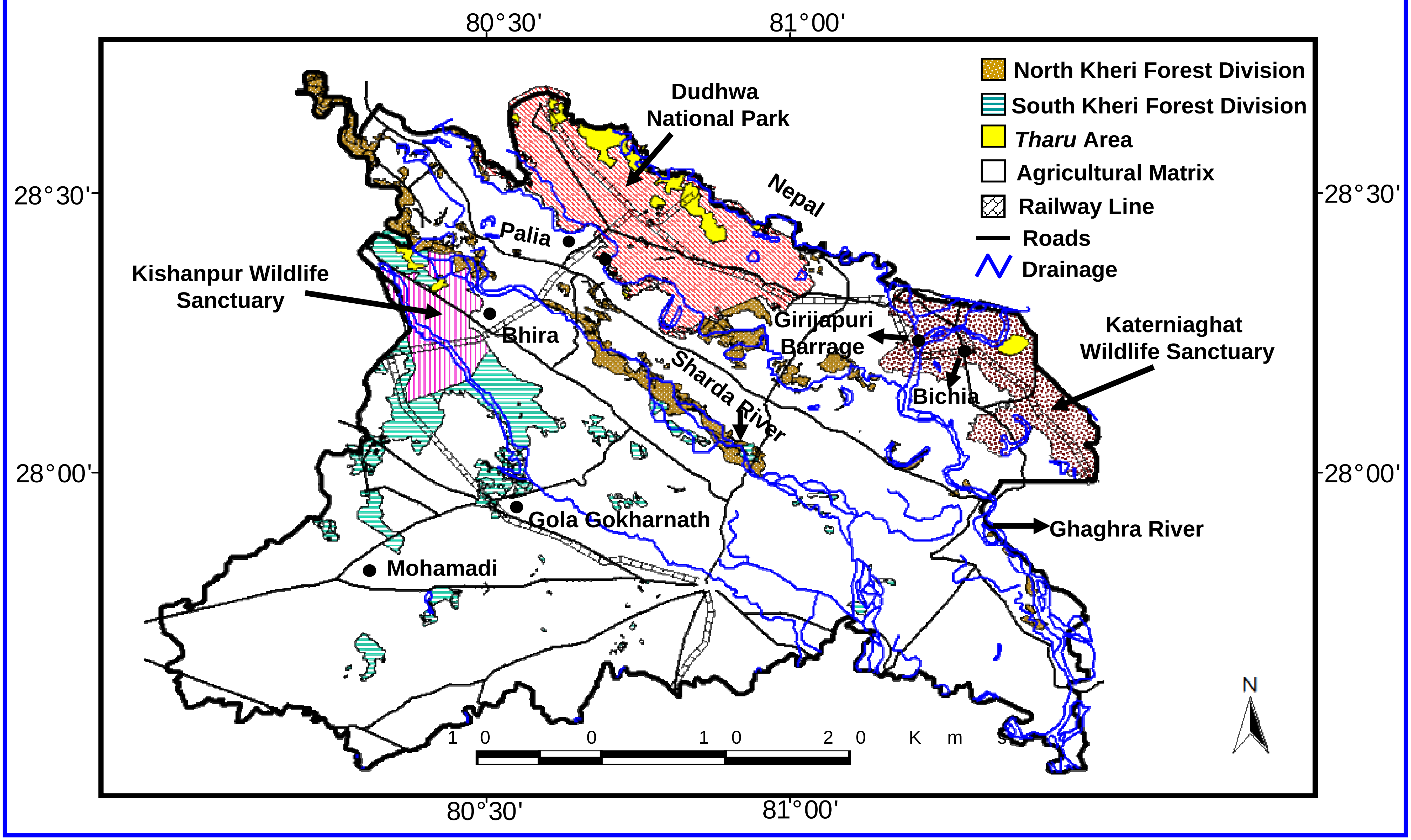


Fig. 2.3 – Prominent Rivers in Dudhwa Landscape

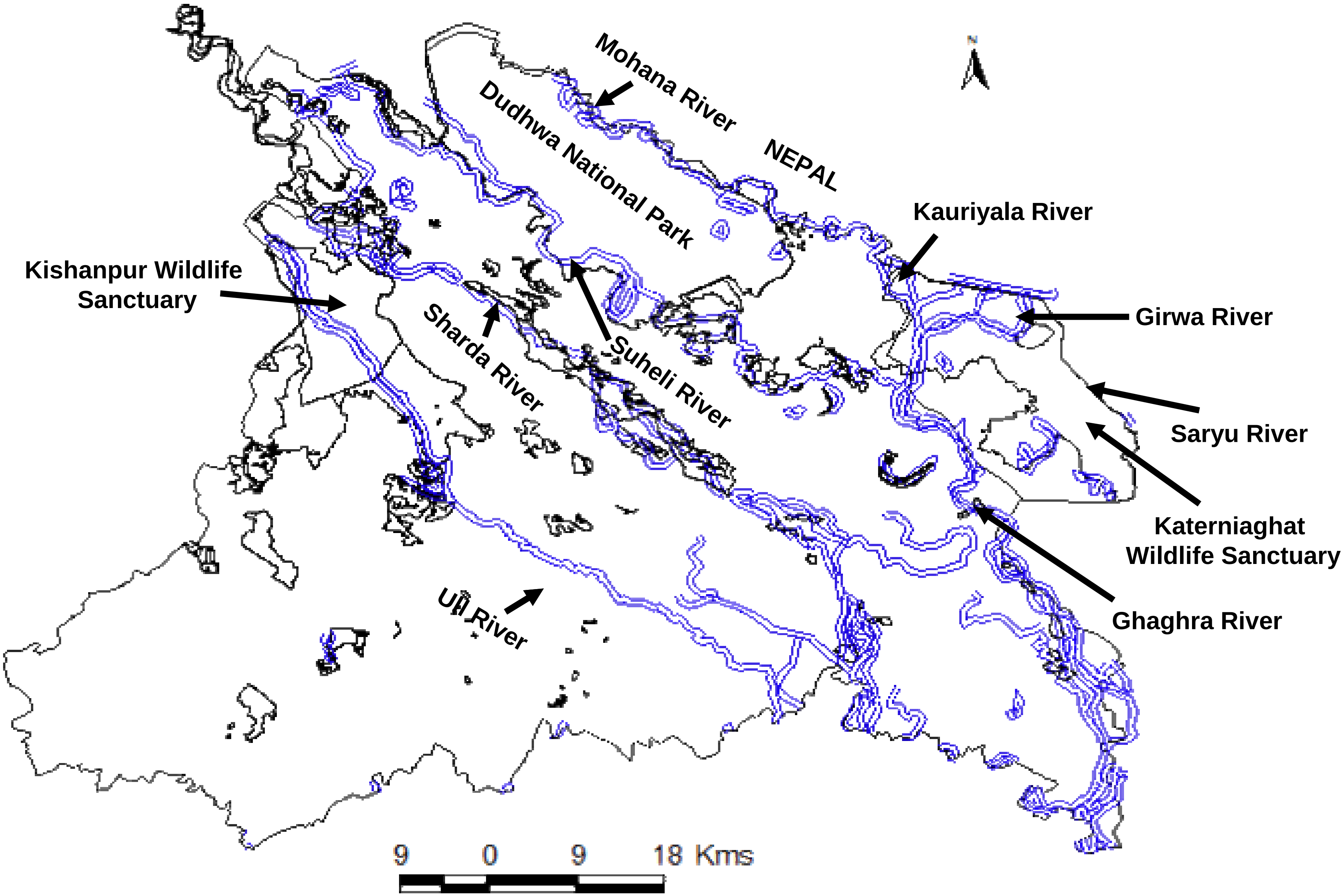


Table 2.1 - Dudhwa Landscape - Constituent Areas and Extent

Constituent Areas	Area (sq km)
Dudhwa National Park (DNP)	490.3
Buffer Area of National Park	190.0
Kishanpur Wildlife Sanctuary (KWS)	203.4
Katerniaghat Wildlife Sanctuary (KAT)	400.6
North Kheri Forest Division (NKFD) and South Kheri Forest Divisions (SKFD)	842.8
Total Forestland	2,127.1
Matrix Land	5966.21
Total Area - Dudhwa Landscape	**8093.31**

The third larger constituent area of the landscape is KAT which is located in Bahraich district which borders Kheri on western side (Fig. 2.1). The boundry is demarcated by a major river of the state i.e. Ghaghra River. Analogously as in DNP, Indo-Nepal border constitutes the northern boundry. The Sanctuary encompasses an area of 400.6 sq km (Table 2.1). The reserved forests of Motipur and Kakraha serve as its buffer. The area was carved out from 'Motipur Reserved Forest' and declared as a Sanctuary in 1976. Till recent past, the KAT enjoyed good connectivity with DNP. However, its connectivity with the Royal Bardia National Park (RBNP) of Nepal in north is relatively maintained. Both the national parks (DNP and RBNP) are within a distance of 12 km from KAT.

Both DNP and KWS together were brought under the purview of the 'Project Tiger' in 1987 as Dudhwa Tiger Reserve and later in the year 2000, area of KAT was also added (De, 2001).

Besides above larger fragments as PAs, several small forest fragments belonging to NKFD and SKFD are also scattered in the landscape north and south of Sharda River, respectively. Cumulatively, area of those fragments is 842.8 sq km (Kumar *et al.*, 2002). Thus, the total forestland including PAs and managed forests (MFs) in Dudhwa landscape amounts to 2,127.1 sq km. The custodian of this forest land is the Uttar Pradesh Forest Department (UPFD) and responsible for its management. In addition, to the larger fragments as PAs and smaller fragments of two managed forests (NKFD and SKFD), the landscape includes matrix of 5966.21 sq km. Thus, the total extent of Dudhwa landscape, study area in the present context is 8093.31 sq km (Table 2.1).

2.3 Physiographic Conditions

The fluvial action of the many rivers and streams disgorging monsoon rainwater from the Himalayan and Shiwalik hill tract creates in the Gangetic Plain a heterogeneous landscape characterized by a mosaic of dense Sal, wet grassland, and shallow seasonal swamps amidst extensively and intensively managed matrix of agriculture.

2.3.1 Topography

The area is a vast alluvial floodplain traversed by numerous rivers and streams flowing in south-easterly direction. There are no prominent eminences, except for level due to low river beds and the high banks which flank the streams on either side. This has resulted in the formation of series of fairly elevated plateaus. The rivers and streams frequently change their courses leaving behind old channels in which water collects to form lakes and swamps. The general slope of the area is from north-west to south-east. By and large, landscape is flat with a narrow range of altitudinal variation (ca. 110 m to 185 m a.m.s.l). In case of DNP, the altitude ranges from 182 m in the extreme north along Mohana River (DNP) to 150 m in south east. In KAT, it varies from 169 m near Chaparia Chowk to 149 m near Motipur Forest Rest House (Jha, 2000; De, 2001). The lowest altitude (114 m) occurs in the furthest south-east corner at the junction of Kauriyala and Dahawar Rivers (Prakash, 1979).

2.3.2 River System and Water Bodies

The landscape is conspicuous by the presence of two prominent rivers (Sharda and Ghaghra), several tributaries (e.g. Suheli, Mohana, Ull, Girwa and Saryu), numerous streams (famous ones – Joraha, Neora, Nagrol, Orai Nala, Maila Nala), and innumerable forest wetlands – swamps (*taal*). Well known swamps in the area are: Bankey, Kakraha, Bhadi, Jhadi, Mahadeva, Puraina. Sustainability of these featured characteristics (a network of rivers, tributaries, streams, and swamps) of the landscape is vital for ecological integrity and economic prosperity in the region (Plate 2.1). Detailed account on the network of rivers, tributaries, streams, and swamps is available in the Gazetteers of District Kheri and Bahraich (Prakash, 1979; Pande, 1988) and management plan of DTR (De, 2001) and KAT (Jha, 2000).

Prominent silt laden rivers rushing downward from Himalayas spread out in the flatter area of the landscape and deposit fertile silt every year during monsoon. This way, the land otherwise burdened with the pressure of burgeoning human population gets a new lease of life. The rich alluvial silt and clay deposits and plentiful of water supply create a belt of productive forests, grasslands, wetlands, and croplands. Large extent and enormous volume of natural vegetation (forest and grassland) present in the landscape plays a valuable role, acting like a 'sponge' to regulate and stabilise water run-off through numerous streams. Streams continue to flow in dry weather and floods are minimized in rainy weather (MacKinnon *et al.*, 1986). Forested wetlands, swamps (*taal*) in present case have a wide distribution. These swamps are quirks and local aberrations of the hydrological cycle which differ from their surroundings by the persistent presence of free water (Paijmans *et al.*, 1985). The word 'quirk' and local aberration' suggest an unusual ecosystem - something deviating from the norm-indeed something deserving studies and possibly conservation. Swamps are undisputedly important in the landscape as they contribute to the local hydrology and also to biodiversity by supporting obligate flora and fauna that are largely restricted to their watery realm (Calhoun, 1999).

Plate 2.1 – Network of Swamps, Streams, and Rivers in Dudhwa Landscape

Bhadi *taal* in DNP

Puraina *taal* in KAT

Swamp (*taal*)

Neora nala in DNP

Maila nala in KAT

Stream

Sharda River in KWS

Girwa River in KAT

River

The landscape constitutes a part of catchment of main river Ghaghra. The chief tributaries which pass through constituent PAs include Suheli and Mohana (DNP); Sharda and Ull (KWS), and Kauriyala, Girwa and Saryu (KAT) (Fig. 2.3). Mohana and Suheli Rivers flow roughly along northern and southern boundaries of the DNP, respectively. Mohana River rises from a swamp in Nepal, follow south-east direction and finally confluence with Kauriyala, a tributary of Ghaghra. Similarly, Suheli River enters the Kheri district from Nepal and flows in a south-easterly direction with a very irregular course along the boundary of the park and finally also joins the Ghaghra River. It changes its course yearly, and its bed varies year after year. In addition, there are many streams or '*nallah*' which add to the river system of the park. There are also a large number of perennial or seasonal *taal* located in the park. Details of the major rivers, streams, and swamps in Dudhwa landscape are presented in Table 2.2.

KWS is associated with two important and large rivers: Sharda and Ull. Contrary to DNP, rivers of the KWS have their origin in India only. The Sharda River, also known as Chauka originates from the Greater Himalayas at Kalapaani at an altitude of 3,600 m in the Pithoragarh district of Uttarakhand, India. On its upper course, it forms India's eastern boundary with Nepal and finally descends in plains of adjacent Pilibhit district and Kheri district. It flows in south-east direction in the Kheri district and forms a part of the north-east boundry of KWS and finally joins with Ghaghra. It flows for a length of 223 km in Nepal and 323.5 km in India up to its confluence with Ghaghra River. Historically, the Sharda River has been known to frequently change its course and carve out a fresh course for itself every year (Prakash, 1979; Pande, 1988). However, in recent decades, the intensity has increased; the river has come close to Jhadi *taal* in KWS jeopardizing the very existence of *taal* itself which is associated with one of the significant sub-populations of highly endangered swamp deer (De, 2001; Midha and Mathur, 2007). The second river, Ull is of considerable size and flows from north-west to south-east through the centre of Kheri district and Sanctuary too. It rises in swamps in Puranpur area of the Pilibhit district. It traverses a large portion of the Sanctuary and finally joins the Sharda River. Its total length is 176 km. Both the rivers swell to a large volume in monsoons causing floods and damage to cultivation of the district. The important swamps of the KWS are mentioned in Table 2.2.

Table 2.2 - Prominent Rivers, Streams, and Forest Swamps of the Constituent Areas

Protected Area	Rivers/Streams/*taal*
DNP	**Rivers -** Mohana and Suheli
	Streams - Joraha, Neora, Nagrol, Donda, Nakhaua
	***taal* -** Bankey Kakraha, Bhadi, Chhedia, Aamha, Khajuria, Pajuha, Bhadraula, Chapra, Puraina, Mutna, Ludaria, Churiala, Nagra, Ranwas
KWS	**Rivers –** Sharda and Ull
	***taal* -** Jhadi
KAT	**Rivers –** Kauriyala, Girwa, Saryu, and Ghaghra
	Streams - Orai nala, Maili nala, Maila nala, Patalchuhi nala, Bhaghar nala, Saryu nala, Gandhaila nala
	***taal* -** Mahadeva, Puraina, Girija, Dhanaura, Khajuha

Source: Jha (2000) and De (2001)

The chief river of the KAT is Kauriyala (with tributaries Girwa and Saryu), which is known as the Ghaghra in lower reaches. The Kauriyala River has its origin in the lower ranges of the Himalaya in Nepal at Chisapani. In Nepal, it is known by the name Karnali, it branches out well into Kauriyala and Girwa before entering India. Kauriyala after separating out, flow to about 30 km, through Bhabar and *Terai* of Nepal, and ultimately enters Bahraich district at its extreme north-western corner. It is here joined by Mohana River from DNP, and then it flows south-east for 11 km to its junction with the Girwa River, at Girijapuri barrage. It receives the Saryu River in the right bank, a short distance above Shitabaghat. In the lower reaches, it is joined by Dahawar and Sharda River. Below Katerniaghat, it is known as Ghaghra River.

Girwa River enters the Bahraich district at the extreme north-east point, and after flowing for about 1 km towards south-west within Katerniaghat range of the KAT, it joins Kauriyala River. The other tributary of Kauriyala, the Saryu River enters the district near a village named Salarpur, a short distance from Murtiha range of sanctuary. It flows along the boundry of eastern buffer of Sanctuary and finally joins Kauriyala. KAT also has a good network of streams which finally end up in any one of the above rivers, the important streams and swamps are mentioned in Table 2.2. A canal from Girijapuri barrage also passes through part of Nishangada forest range of the KAT.

It is noteworthy to mention here that agriculture intensification has extended right up to the boundaries of larger forest fragments or three constituent PAs. Farmers have maximised production by undertaking multiple crops round the year. The '*Rabi*' crops e.g. Wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), peas (*Pisum sativum*), gram (*Vigna radiata* and *V. mungo*) and few lentils during winter and other summer crops require irrigation and for this ground water is being exploited heavily using electric/diesel pumps. This enhanced ground water use and gradual accumulation of silt over forest swamps located on peripheral areas have drastically reduced their water retention capacity and other associated aquatic values.

2.3.3 Soil

The soil of the area consists of recent alluvial formation of the Gangetic Plain showing a succession of sand and loam beds, varying in depth according to the configuration of the ground (De, 2001). The following broad types of soil can be seen in landscape:

a) *Low alluvium*- The soil is almost pure river sand, enriched in many places by a deposit of fine silt. This is found in bed of Sharda, Ull, Kauriyala, and Saryu.
b) *Middle alluvium*- It is of earlier origin than the low alluvium, the soil is sandy but has a certain amount of decaying vegetable matter.

c) *High alluvium***-** following types of soils are found:

- A light sandy loam with a variable proportion of clay. It supports the best tree growth and is found in Sal forests. The soil has a fair amount of humus.
- A heavy loam with varying proportion of clay and fair amount of vegetable matter. The soil is fairly fertile, but inferior to light sandy loam. It supports good crop of Sal, and where clay proportion is more, *Terminalia alata* is predominant species. It can be found in Nishangada range of KAT.
- A stiff infertile clay containing manganese dioxide and with reef of kankar, many of which have become exposed as a result of erosion. It can be seen in Dharampur and Murthiha forest range of KAT.

2.3.4 Climate

The climate of the area is tropical monsoon type and is characterized by a dry hot summer and a pleasant cold season. The year may be divided into four distinct seasons (Prakash, 1979; Pande, 1988). The cold season or winter lasts from about the end of November to the end of February, followed by the summer season from March to the third week of June. The period from last week of June to the end of September is south-west monsoon season and October till November constitute the post-monsoon season.

Notably, the landscape depicts two distinct situations: firstly, three large forest fragments pre-dominated by natural vegetation – dense woodland and tall grassland, and numerous streams and swamps, and overall high level of moisture regime while second, contrast situation in drastically altered matrix away from forest fragments. The second situation obviously is devoid of natural vegetation, moisture regime and water availability due to presence of just crop fields. Apparently, above two situations depict varying micro-climatic conditions. Information on climatic data for two districts of study area is available in respective District Gazetteers (Prakash, 1979; Pande, 1988). In case of Kheri, the oldest data dates back to 1870. Broadly, data on rainfall, minimum and maximum temperature, and humidity are available. Hence, climatic patterns on these three driving variables can be ascertained for the past. Consultation of old Forest Working Plans of NKFD and SKFD revealed that the climatic data (rainfall and temperature) used to be collected at atleast 8-10 different stations located in various forest ranges (Pant, 1990; Srivastava, 1993; Srivastava, 2000). Data in forest ranges dates back to 1936. Climatic data in landscape is also being collected by the Irrigation department and the M/S Bajaj Hindustan Sugar Mills Limited (BHSML) at select locations (Mohamadi, Gola Gokharnath, and Palia). Recent updated information on rainfall in two districts was obtained from the Department of Agriculture and Directorate of Economics and Statistics, Govt. of Uttar Pradesh. Recent forest and wildlife management plans revealed that unfortunately much desired systematic data on climatic variables has been discontinued by different forest ranges in recent times despite its immense value (De, 2001; Kumar *et al.*, 2002). Following synthesis highlights a gist of recorded values and observed trends based on information from above sources.

The landscape experiences extremes of temperature and humidity during different seasons. Nights during winter are cold and foggy. Usually fog sets in evening hours, after sun set and persist until about middle of the next day. There is a heavy dew fall during winter months and the vegetation remains damp. Frosts occur frequently during December to middle of February. These are attributed to the general cooling effects of the cold winds that flow down to Sharda Valley and are most severe in open grassland. Trends on three driving variables are presented below:

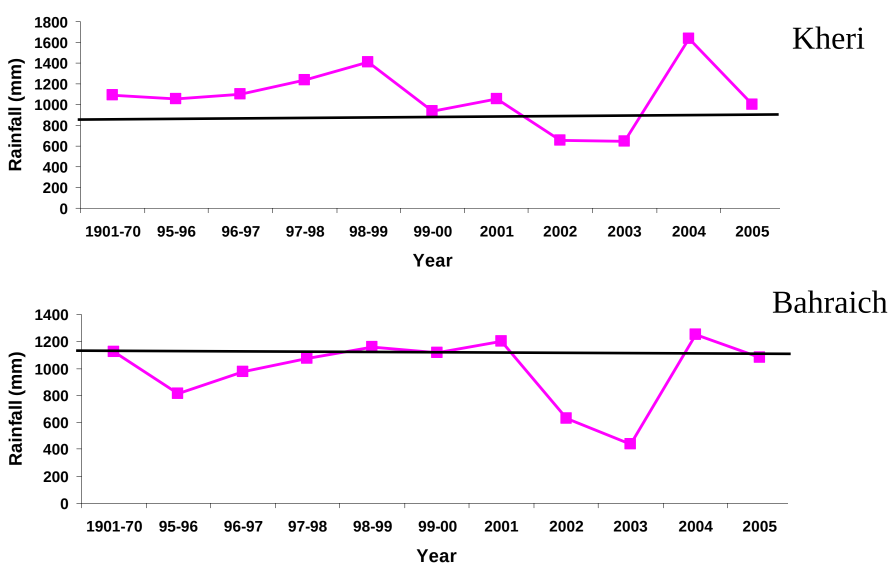
Rainfall: Available data sets for long periods provided values of average annual rainfall ranging from 813 mm to 1,386 mm (Table 2.3). Precisely, average rainfall for Kheri and Bahraich districts for a period of 105 years (1901 – 2005) recorded were 1,090 mm and 1,105 mm respectively (Fig. 2.4). The average rainfall for Gola Gokarnath for 40 years period (1959-1998) was 1,349 mm. The monsoon advances into the area by about the last week of June and withdraws by the end of September. About 85-90% annual rainfall is received during the monsoon season; July and August are the wettest months. Usually November and December are the driest months. Small quantity of winter rains due to south-west monsoon or due to western disturbances is also received. In general, rainfall increases from the south-west to the north-east in the landscape. On an average there are about 48 rainy days in a year. As high as 409 mm rain on a single day at Kheri on August 31, 1870 and 423 mm at Kaisarganj, Bahraich district on September 25, 1901 were recorded. In some exceptional years, annual rains exceed as high as 190% of the normal year.

Temperature: The monthly average values of minimum and maximum temperature recorded at Kheri and Bahraich are provided in Table 2.4. Decadal values starting from 1959 are also provided in case of Gola Gokarnath. The winter starts by about the end of November when the temperature commences falling rapidly. January is the coldest month with the mean daily maximum and minimum temperatures at 22-23°C and 8.5-10.2°C respectively (Fig. 2.5). In association with the cold waves arising in the wake of the western disturbances which travels east-wards, the minimum temperature goes down to about 3°C and at times even leads to frosts. From about the end of February the temperature begins to rise rapidly. May is the hottest month with the mean daily maximum and minimum temperature at 40-45°C and 25.5°C, respectively. The weather in summer is intensely hot and on individual days the maximum temperature occasionally reaches over 46°C. Hot and dust laden winds occasionally blow adding to the discomfort. With the advent of the monsoon in the last week of June, there is an appreciable decrease in the day temperature, but the night temperature remains as high as during summer. With the increased moisture in the air during the monsoon seasons, despite the decrease in day temperature, the weather is often oppressive in between the rains. In September, there is slight increase again in day temperature. After the withdrawal of the monsoon by about the end of September, both day and night temperature decrease progressively.

Table 2.3 - Average Annual Rainfall in Kheri and Bahraich Districts (values in mm)

Period	Kheri	Gola Gokharnath	Nighasan	Mohamdi	Overall Kheri	Overall Bahraich	Source
1870-1959	1,070	-	1,155	980	1,068		Prakash, 1979
1959-1968	-	1,151	-	861	-		Kumar *et al*., 2002
1969-1978	-	1,386	-	1,096	-		Kumar *et al*., 2002
1978-1988	-	1,076	-	813	-		Kumar *et al*., 2002
1989-1998	-	975	-	952	-		Kumar *et al*., 2002
1901-1950	-	-	-	-	-	1135	Pande, 1988
1901-2005	-	-	-	-	1,090	1,105	Dept. Agriculture*, U.P.

**Department of Agriculture and Directorate of Economics and Statistics, Govt. of Uttar Pradesh, India*

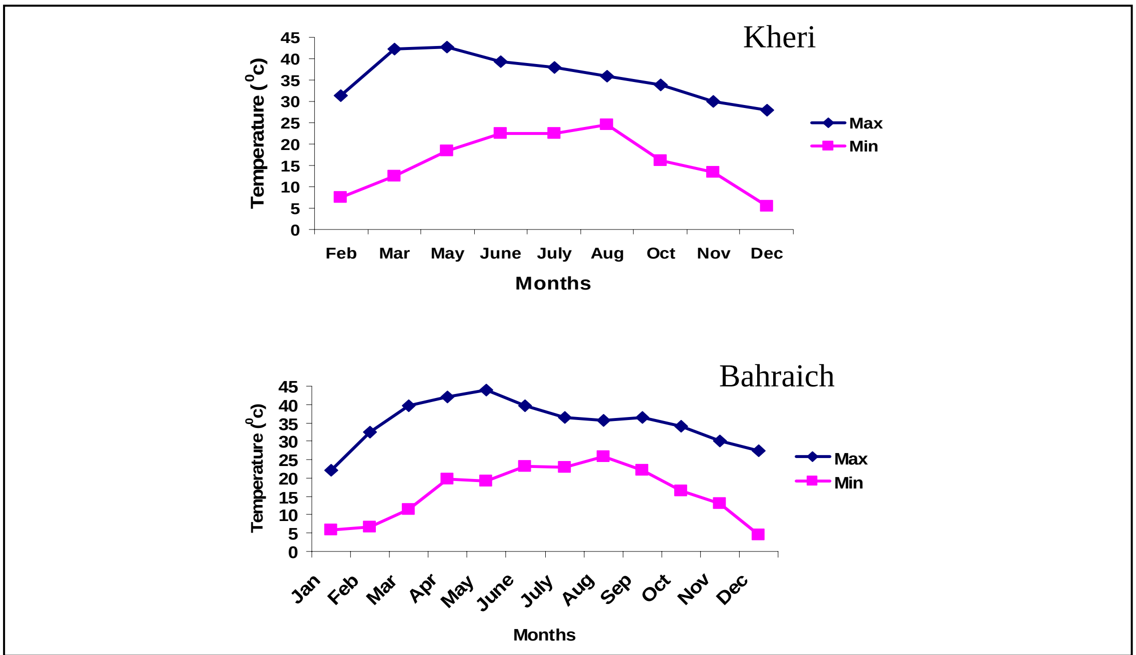


Source: Department of Agriculture and Directorate of Economics and Statistics, Govt. of Uttar Pradesh, India

Fig. 2.4 - Annual Rainfall for Kheri and Bahraich Districts from 1901 to 2005 (Values in mm)

Table 2.4 - Monthly Values of Mean Maximum and Minimum Temperatures at Different Locations in Dudhwa Landscape (Values in °C)

Month	Temp	Kheri	Gola Gokharnath				Bahraich
		1870-1950	1959-1968	1969-1978	1979-1988	1989-1998	1901-1950
January	Max.	22.1	21.7	23.1	20.9	19.6	22.6
	Min.	9.1	12.6	8.8	10.2	8.4	8.8
February	Max.	25.9	26.0	28.8	24.1	23.3	25.6
	Min.	10.8	12.6	9.6	11.6	10.7	10.9
March	Max.	31.8	31.5	35.6	29.8	28.7	31.9
	Min.	16.0	17.5	13.7	16.8	15.8	15.4
April	Max.	37.6	37.9	41.0	36.5	35.7	37.4
	Min.	20.9	25.5	20.1	23.3	19.5	20.9
May	Max.	40.3	40.3	42.7	37.8	40.7	39.8
	Min.	25.4	26.7	22.7	26.1	23.5	25.6
June	Max.	37.7	38.0	41.9	37.3	38.6	37.6
	Min.	26.3	27.9	21.2	27.8	27.2	27.0
July	Max.	32.7	34.0	37.2	34.1	33.8	33.0
	Min.	25.8	26.9	24.4	26.6	22.6	26.3
August	Max.	32.1	33.4	36.6	34.6	34.6	32.2
	Min.	25.6	26.3	24.0	26.7	26.4	26.1
September	Max.	32.7	33.9	35.4	34.1	34.6	32.7
	Min.	24.8	25.4	23.3	25.6	24.6	25.1
October	Max.	31.7	32.0	34.8	32.2	32.7	32.1
	Min.	20.1	21.1	19.4	21.7	21.0	20.7
November	Max.	28.5	27.3	30.3	27.9	28.1	28.6
	Min.	13.0	14.8	13.0	16.0	16.6	13.4
December	Max.	24.3	22.7	24.7	22.5	22.7	24.3
	Min.	9.8	10.4	9.0	10.9	10.5	9.4



Data not available for the month of January, April, and September for Lakhimpur-Kheri district
Source: Economics and Statistics Division, Govt. of Uttar Pradesh, India

Fig. 2.5 - Mean Monthly Temperature at Kheri and Bahraich Districts During 2005

Humidity: From March to May the air is least humid, it being about 50 per cent in the morning and about 30 per cent in the evening. During the rest of the year it is otherwise, the humidity being nearly 70 per cent or above in the morning and nearly 50 per cent in the evening (Table 2.5).

Table 2.5 - Relative Humidity at Kheri and Bahraich Districts (Values in %)

Month	Kheri (1870-1950)		Bahraich (1901-1950)	
	8.30*	17.30	8.30*	17.30
January	83	64	82	57
February	74	48	74	47
March	63	37	55	32
April	44	25	43	24
May	47	27	50	31
June	69	49	68	51
July	86	75	81	73
August	88	79	83	77
September	84	75	80	72
October	79	65	73	57
November	75	60	72	51
December	81	63	79	56
Annual	73	56	70	52

** Hours according to Indian Standard Time*
Source: Prakash (1979) and Pande (1988)

2.4 Vegetation

Respective district gazetteers provide a very brief general account of flora in Kheri and Bahraich district (Prakash, 1979; Pande, 1988). Accordingly, the greater part of the two districts in the north is covered with forests. Even today, bulk of the forest in Kheri occur in north of Sharda River. Small proportion exists south of Sharda River in much smaller patches, mainly upto Ull River. Sal has been described as the principle tree of the forests found here. A large number of groves (ca. 8,000), the smallest being <0.4 ha in area have also been reported in the earlier times. A quality information on the forest diversity, extent, management history and silvicultural prescriptions is available through the old Forest Working Plans (NKFD – Kakkar 1964, Chandra 1973, Gaur 1982, Srivastava 1993; SKFD – Chandra 1972, Rizvi 1980, Pant 1990, Srivastava 2000 and Motipur Reserve), and Wildlife

Management Plan (Singh, 1982; Jha, 2000 and De, 2001). Champion and Seth (1968) described the vegetation of the area in four groups (Tropical Semi-Evergreen Forest, Tropical Moist Deciduous Forest, Littoral and Swamp Forest, and Tropical Dry Deciduous Forest) and more than a dozen forest/edaphic types (Jha, 2000 and Kumar *et al.*, 2002). The quality of information on other than trees and shrubs remained inadequate/weak in working plans. The first time systematic information on plant diversity for the area was presented in the form of a 'Flora of Dudhwa National Park' by Singh (1997). This flora provides a general account of vegetation along with detailed floristics on 821 angiosperms taxa documented from the DNP and adjoining areas of Kheri.

Pure Sal and Sal dominated forests occupy major area. Some of the best Sal forests occur on higher alluvial terraces ('damar') with loamy soil. Sal is the most dominated species in the landscape. Prominent co-associates are *Mallotus philippensis, Terminalia alata, Lagerstroemia parviflora, Trewia nudiflora, and Mitragyna parvifolia*. Profuse growth of *Syzygium cumini and Schleichera oleosa* occurs along streams. The forest undergrowth mainly consists of *Clerodendrum viscosum, Colebrookea oppositifolia, Murraya koenigii, Ardisia solanacea, Flemingia macrophylla and Glycosmis pentaphylla*. The common climbers are: *Tiliacora acuminata and Bauhinia vahlii*. Woody climber *T. acuminata* forms a dense carpet on ground. *Calamus tenuis* also occurs in moist places along streams. Teak was planted in several places by clear felling as well as gap planting. Prominent grasses observed in Sal forests are *Desmostachya bipinnata, Themeda arundinacea, Saccharum bengalense, Saccharum spontaneum,* and *Imperata cylindrica.*

Besides Sal forests, Moist Mixed Deciduous Forests having prominence of miscellaneous species and conspicuous absence of Sal occur on sandy alluvium. *Terminalia alata, Haldina cordifolia, Braussonetia papyrifera*, and *Millusa velutina* are main constituent trees. *C. viscosum, G. pentaphylla*, and *Ardisia solanacea* make prominent shrubs for these forests. The Tropical Seasonal Swamp Forest dominated by *Barringtonia acutangula* and *S. cumini* occur in swampy depressions along streams which remain under water continuously for a long period during rains or where deep black heavy waterlogged soils occurs. *B. acutangula* dominated forests occur along Suheli and Ull Rivers. *S. cumini* forms dense crop with long clean boles. The landscape was once famous for its Khair (*Acacia catechu*) and Sissoo (*Dalbergia sissoo*) type forests. They occur on new sandy alluvium along streams and rivers. Flooding and prolonged water logging result into poor and stunted growth of Khair and Sissoo. *Bombax ceiba, Haldina cordifolia* and *Catunaregam spinosa* are main co-associates. *Cassia tora, Curculigo orchioides* and *Dioscorea belophylla* are prominent herbs.

The area is popular for extensive plantations of Khair, Shisham, *Ailanthus excelsa*, Teak, and *Eucalyptus citridora*. *Lantana camara* is one prominent exotic weed. *Cassia tora* and *Parthenium sp.* are common in excessive grazed and village peripheral areas.

Grasslands occur in openings within woodland. They are locally known as '*phanta*' and occupy large stretches and lie scattered in between the Sal forests. In addition, tall grasslands also occur in depressions and seasonally inundated/waterlogged areas. Grasslands in the landscapes are included in the *Phragmites – Saccharum - Imperata* grassland type as per Dabadghao and Shankarnarayan (1973). Grasslands are annually burnt. Tall grasslands in *Terai* are described as stages in the succession continuum between the primary colonization of new alluvial deposits by flood climax deciduous Sal forests (Lehmkuhl, 1989). Fluvial processes and human actions remain the primary disturbance responsible for the maintenance of grasslands in the tract. Abundance of large herbivore fauna has been historically common to these grasslands. Forested tract is dotted with widely scattered swamps. A vast diversity of aquatic and marshy vegetation from such sites has been described.

Away from natural vegetation in cultivation areas, prominence of several cereals, pulse, vegetable, and other cash crops is found in different seasons. Rice, wheat, maize, and sugarcane crops predominantly occupy matrix. Singh

(1997) has described 57 plants of ethnobotanical significance to local communities, particularly '*Tharu*'.

Singh (1982) for the first time used satellite imagery of Landsat of 1981 and provided area statistics of different vegetation types. Kumar *et al.* (2002) identified 17 land use types using IRS 1B LISS II data of 1997 in DNP and KWS. It included five types of Sal forest (Dense Sal Forest, Moderately Closed Sal Forest, Open Sal Forest, Sal Mixed Forest, and *Chandar* Sal Forest), five other prominent forest types including plantations (Moist Mixed Deciduous Forest, Tropical Semi-Evergreen Forest, Tropical Seasonal Swamp Forest, Khair and Sissoo forests, Tamarix scrub), two types of grasslands (Upland and Lowland), three types of wetland (Swamps, Rivers, and Sandy Banks), and agricultural area. The study also provided vegetation structure and composition database of DNP and KWS.

2.5 Fauna

Owing to the complexity of habitat diversity and ample food, cover and water, the area offers a wide range of faunal diversity (Plate 2.2). The current species richness documentation indicates 47 mammals, 10 amphibians, 35 reptiles, 79 fishes, and, nearly 449 birds (De, 2001, Kumar *et al*., 2002). The area harbours a significant population of tiger (*Panthera tigris*). Jhala *et al*. (2008) reported that the DTR constitutes the major population of tiger in Uttar Pradesh. Another notable feature of the landscape is the existence of five species of deer out of seven species found in the country namely sambar, cheetal, swamp deer (*Cervus duvauceli duvauceli* Cuvier), hog deer, and barking deer (De, 2001). Out of five, the northern swamp deer is endemic to the Indian sub-continent and is listed in the IUCN Red Data Book of threatened species as endangered. It is also home to many other critically endangered species such as hispid hare (*Caprolagus hispidus*), bengal florican (*Hubraopsis bengalensis*) and the reintroduced great Indian one-horned rhinoceros (*Rhinoceros unicornis*).

Plate 2.2 - Species of Conservation Concern in Dudhwa Landscape

Tiger (*Panthera tigris*)

Asian elephant (*Elephas maximum*)

Rhinoceros (*Rhinoceros unicornis*)

Swamp deer (*Cervus duvauceli duvauceli*)

Bengal florican (*Hubraopsis bengalensis*)

2.6 History of Forest Management

Forests in the landscape came under the control of Government in 1861 when a Conservator of Forests was appointed for their management using forest working plans. The management aim included commercial production of wood products and provisioning of subsistence needs of the local people. The important commercial species were *Shorea robusta*, *Acacia catechu, Dalbergia sissoo,* and *Syzgium cumini*. During this period, extensive plantations were also raised in gap areas or after clear felling of Sal or mixed forests. Exotic species like *Tectona grandis and Eucalyptus citriodora* were introduced to this tract. Massive road and railway network was established, both in the National Park and Wildlife Sanctuaries primarily for the purpose of extraction of timber (Plate 2.3). De (2001) mentioned that till presently metalled road network traverse 85 km and 10 km in DNP and KWS, respectively. In addition, several dirt roads or forest roads which connect all important places in the forest reserve were also made. These roads are still used for monitoring and patrolling and during the fire season they serve as effective fire breaks. In total, the dirt roads traverse a total of 897 km stretch of DNP and KWS. Together with such a vast and well maintained network of both metalled and dirt roads, railway tracks also pass through the heart of DNP and cross through both the sanctuaries. These railway lines were also laid in the pre-independence period for the extraction of timber. Presently, the track also traverses a considerable length of 34 km and 11 km within the national park and KWS, respectively. Likewise, much of the KAT is also transerved by railway line and road which divide the PA in two parts. Till the establishment of erstwhile Dudhwa WLS in 1968, wildlife was considered important, but secondary to the production of wood and forage.

A substantial change occurred after the post-independence in 1947. Large number of people were resettled from Pakistan and provided with private forests, grasslands, and wetlands to clear and drain. Changing land use policy, uncontrolled expansion of agriculture, large-scale reclamation/conversion of grassland and swamp habitats, heavy deforestation, and enhanced resources dependence on forests altered the

Plate 2.3 – Development Activities in Dudhwa Landscape

Massive Road and Railway Network was established during British era especially for the extraction of Timber

There are large numbers of dirt road which pass through both forests and grasslands and connect all important places, and also serve as fire break

Rai

Few Development Activities after Independence

Girijapuri Barrage, KAT

State Farm within KAT

equilibrium between forests and adjacent agriculture lands. The increasing human pressure and conservation awareness resulted in establishment of relatively small (16 sq km) Sonaripur WLS in 1958 with the aim to protect relict population of swamp deer. The area was increased in 1968 and was renamed as Dudwa WLS. Furthermore, areas of NKFD were added and it was declared DNP. To further protect swamp deer, part of area of SKFD was earmarked as KWS in 1981. Both DNP and KWS together were brought under ‘Project Tiger’ in 1987 as Dudhwa Tiger Reserve and later area of KAT was also added in 2000 (De, 2001; Kumar *et al*., 2002).

2.7 Socio-Economic Situation

The land in between the three PAs is mainly under private ownership. Rapidly increasing human population and its increasing demands have resulted into rampant encroachment of remaining forestland and conversion or reclamation of swamps for agricultural purposes. Biotic pressure from the local population which traditionally depends upon the forest resources for sustenance and livelihood has greatly increased. De (2001) listed 125 villages in and around (5 km boundry) of DNP and KWS and noted the pressure being exerted by 1,89,163 persons with their 80,000 livestock on two PAs and their buffer. This has resulted into enhanced man-wildlife conflict.

(a) Population trends

The enumeration of the population in both the districts started during Avadh census of 1869. The available figures indicate that in Kheri district, except for the period from 1911 to 1921, when the population recorded a fall, due to epidemic, like influenza and migration, there had been a continuous rise in numbers (Prakash, 1979). The lowest increase of 3.35 % was registered in the decade of 1941-1951 and the highest, being 32.38% in the decade of 1991-2001. The significant increase of the decade (1991-2001) was even higher than as found for the state, being 25.80% (Table 2.6). Analogously, Bahraich district also reported incessant population growth from 117 persons/sq km in 1901 to 415 persons/sq km in 2001 (Table 2.6). Albeit, the disparity in area of the district between years exists, total population and density evinced that there had been continuous increase.

The figures indicated that growth in both districts was not spasmodic, but well sustained. Interestingly, till 1951, the percentage decadal variation was less than 10%, but after that there was a rapid growth in the population. The reasons could be attributed to large scale immigration from Pakistan after partition. Some Muslim families from the district migrated to Pakistan while some Hindu families came over. The total number of such migrants according to 1961 census was 1,375 in Bahraich and 2,315 in Kheri district. In addition, families from Bengal, Burma, and East Punjab were also rehabilitated in the district. Families were provided with a house, cultivated land, agricultural implements, seeds, manure, along with the facilities of drinking water. The land allotted to these people was either 'Gram Samaj' land or on the land alloted by government for the purpose (Prakash, 1979; Pande, 1988).

Table 2.6 - Population, Density, and Percentage Decadal Variation in Kheri and Bahraich Districts of Uttar Pradesh from 1901 to 2001

Year	Lakhimpur-Kheri			Bahraich			U.P.
	Persons	Density** (persons/ sq km)	% Decade Variation	Persons	Density*** (persons/ sq km)	% Decade Variation	% Decade Variation
1901	9,05,158	117.50	-	10,49,710	152.1	+4.92	-
1911	9,59,225	-	+5.97	10,45,775	-	-0.37	-1.36
1921	9,13,496	-	-4.77	10,63,222	-	+1.67	-3.16
1931	9,44,502	-	+3.39	11,34,082	-	+6.66	+6.56
1941	10,24,051	-	+8.42	12,38,098	-	+9.17	+13.57
1951	10,58,373	-	+3.35	13,43,660	-	+8.53	+11.78
1961	12,58,433	-	+18.90	14,99,929	-	+11.63	+16.38
1971	14,86,590	-	+18.13	17,26,972	-	+15.14	+19.54
1981	-	-	-	-	-	+24.98	+25.39
1991	-	315*	+23.89*	-	320*	+25.19*	+25.55
2001	32,00,137*	417*	+32.38*	23,84,239*	415*	+29.55*	+25.80

*Source: Uttar Pradesh (U.P.) District Gazetteers, Kheri and Bahraich District, Govt. of Uttar Pradesh, India; *Source: Census of India, 2001; **Area of Kheri District: 7,680 sq km; ***Area of Bahraich District in 2001 was 4, 420 sq km, from 1901 to 1977; it was 6, 810 sq km;*
- : Data not available

The areas of Nepal abutting the National Park are rural with villages dotting the landscape. The agricultural field extend up to the no-man's-land on the Nepal side. DNP is elongated in shape and thus receive a large PA - people interface. There are no major habitations in the Park except 5.78 sq km forest land under eleven different small encroachments. Among these encroachments, the most prominent one is Surma village wherein 69 families stay. The core area of park is surrounded by 190 sq km of buffer on northern and southern side. The northern buffer (124 sq km) lies between the core and international border. It enclaves 37 revenue villages inhabited by '*Tharu*'. The southern buffer (66 sq km) lies between core and peripheral villages on Indian side. The forested buffer is highly fragmented. Analogously, KWS also face anthropogenic pressure from peripheral human settlements but unlike DNP, it receives only from northeastern side. The western side is bounded by Kheri Branch Canal of the Sharda Canal System and the rest sides are bounded by forests of SKFD and Shahjahanpur Forest Division. Within Sanctuary, two villages namely Chaltua and Kishanpur have encroached only 34 ha of area.

(b) Land use

The favourable conditions in terms of plain land, fertile soil, high water table, cheap labour, and improved agricultural practices conspired to make the agriculture the mainstay of local economy of both the districts today. Currently, more than 60% of the land is under plough or net sown in both the districts. Table 2.7 present the land use pattern in Kheri and Bahraich districts for the year 2004-2005.

(c) Agriculture and irrigation

Table 2.8 presents decennial figures of cultivated area from 1901 to 2001 for both the districts. For Bahraich, except for little decline in few initial years (1901-1931), cultivated area had been adding up continuously. There has been an incessant increase in cultivated area. The maximum increase in both districts occurred during the period of 1951-1961. The reasons could be attributed to explanation given above as large immigration of the people took place during this time period.

The district gazetteers stated the total cultivated area in Bahraich in the year 1858 was 2,06,548 ha which was only 35% of the area of the district. At the settlement of 1898, the total cultivated area increased to cover 59% or 3,56,419 ha area of the district. This increase primarily came from reclamation of forestland. Since the settlement increased further, the cultivated area in 1901 showed an extension of 37,978 ha, bringing the total up to over 65%.

Table 2.7 - Land Use Pattern in Kheri and Bahraich District for the Year 2004-2005

Land use	Kheri		Bahraich	
	Area (sq km)	%	Area (sq km)	%
Total Geographic Area	7680	-	4420	-
Reporting area for land utilization	7710	-	4860	-
Forests	1648	21.37	677	13.93
Not available for land cultivation	793	10.28	588	12.09
Permanent pastures and other growing lands	9	0.11	4	0.08
Land under miscellaneous tree crops and groves	54	0.70	66	1.35
Cultural Wastelands	32	0.41	28	0.57
Fallow land other than current fallows	42	0.54	62	1.27
Current fallows	268	3.47	185	3.80
Net area sown	4864	63.08	3249	66.85

Source: DACNET Project, Ministry of Agriculture, Govt. of India

Crops: The most widely cultivated *Kharif* crop in both the districts is paddy (*Oryza sativa*). It covered about 35% of cultivated area in Bahraich district in 2002-03 (Table 2.9). The high rainfall in the region makes it a suitable area for its cultivation. There has been an enormous increase in extent of paddy cultivation during the last few decades. In 1972-73, net sown area in Kheri district was 1,29,677 ha, it has risen to 1,72,939 in 2002-03 (Table 2.10). Similarly, in Bahraich district, % of area covered under paddy has risen from

25% in 1972-73 to 36% in 2002-03 (Table 2.9). The opening of the canals and cultivation of high yielding varieties has made rice cultivation popular.

The next *Kharif* crop in order of importance and area sown is maize (*Zea mays*) (Tables 2.9 and 2.10). It is most suited to the drier parts of lowland of Sharda and Ghaghra. The other *Kharif* crops deserving mention are bajra (*Pennisetum typhoides*) and jowar (*Sorghum bicolour*). They are grown in inferior soils and narrow strips of sandy land along river banks.

Table 2.8 - Cultivated Area in Kheri and Bahraich Districts from 1901 to 2003

Year	Cultivated Area (ha)	
	Kheri	Bahraich
1901	-	3,99,213
1911	-	3,96,303
1921	-	3,87,689
1931	-	3,82,069
1941	3,40,195	3,97,549
1951	-	4,12,311
1961	4,13,128	4,39,169
1971	-	4,48,819
1974	4,36,014	-
1977	-	4,60,704
2000	4,79,913	-
2001	4,86,400	3,24,900*
2002	4,79,215	-
2003	4,83,370	-

Area of Kheri district: 7680 sq km
- : Data not available for this period
**Area of Bahraich district in 2001 was 4,42,000 ha, for rest of the period (1901-1977), it was 6, 87,100 ha*

In Kheri district, *Kodon (Eleusine corocona)* was one of the favourite *Kharif* cereals up to the fifties of the last century. It occupied an area of 34,617 ha in the district in 1903-04. In the following years, *Kodon has* yielded place to the more remunerative crops like rice and sugarcane. ‘Green Revolution’ with its introduction of scientific methods in agriculture accelerated the process. The area under *Kodon* came down from 25,899 ha in 1951-52 to 8330 ha in 1971-72 (Prakash, 1979). Similar was the case with Bahraich district. Other *Kharif* cereals like *sawan*, *mandua* and pulses like *urd*, *moong*, and *moth* have also lost their popularity to more valuable crops like rice, maize, and sugarcane.

Among *Rabi* crops, wheat (*Triticum aestivum*) heads the list in both districts in terms of area (Tables 2.9 and 2.10). In Bahraich district, it covered 36% area in 2002-03, thus topping the list (Table 2.9). Analogously, in Kheri district, it covered more area than the most suited crop of this region i.e. paddy but fell behind only the sugarcane (Table 2.10). The area under wheat has no doubt increased in last few decades due to introduction of high yielding varieties in late 1960s during the ‘Green revolution’; but the old practice of sowing it mixed with other crops, a characteristics feature of this district has not altogether disappeared. The wheat crop requires a good soil, careful tillage and an assured supply of water.

Table 2.9 - Crop Production of Bahraich District During the Year 1972-73 and 2002-03

Crop	**1972-73**			**2002-2003**		
	Area sown (ha)*	**Yield (q**/ha)**	**% of area***	**Area sown (ha)***	**Yield (t***/ha)**	**% of area***
Rice	1,72,294	5.60	25.07	1,57,356	1.43	35.60
Maize	1,45,356	7.37	21.15	87,457	1.22	19.78
Wheat	1,47,649	8.25	21.48	1,58,907	2.47	35.95
Barley	24,879	5.33	3.62	1,151	2.46	0.26
Sugarcane	5,424	0.78		24,247	50.43	5.48

**Area of district in 2002-03 was 4,42,000 ha and in 1972-73 it was 6,87,100 ha*
***q: quintal (100 kg); ***t: tonnes*
Source: SDDS-DES, Ministry of Agriculture and AGRID-NIC, Ministry of Communications & IT, Govt. of India

Barley (*Hordeum vulgare*) was a favourite *Rabi* crop next to wheat in the past, and it maintained its hold till the fifties of the last century. Thereafter, the area under it began to decline. In 1972-73, it covered an area of 12,963 ha in Kheri district but by 2002-03, it restricted itself to only 648 ha (Table 2.10). Similarly, in Bahraich, % area covered dropped from 5% in 1972-73 to 0.26% in 2002-

03 (Table 2.9). Wheat, gram (*Vigna radiata* and *V. mungo*), peas (*Pisum sativum*), which are paying *Rabi* crops have taken its place. Other important *Rabi* crops include gram, pea, *masur*, and *arhar* which are sown in these districts.

Table 2.10 - Crop Production in Kheri District During the Year 1972-73 and 2002-03

Crop	1972-73		2002-2003	
	Area sown (ha)	Yield (q*/ha)	Area sown (ha)	Yield (t**/ha)
Rice	1,29,677	6.09	1,72,939	2.11
Maize	34,448	8.42	9,898	0.85
Wheat	1,36,534	8.42	1,95,218	2.70
Barley	12,963	6.65	648	1.74
Sugarcane	80,452	371.01	2,24,036	53.59

**q: quintal (100kg); **t: tonnes*
Source: SDDS-DES, Ministry of Agriculture and AGRID-NIC, Ministry of Communications & IT, Govt. of India

Sugarcane (*Saccharum officinarum*), oil-seeds like groundnut (*Arachis hypogea*), linseed (*Linseed usitatissimum*), *til*, and mustard (*Brassica campestris*), vegetable and fruits, sun hemp, jute, tobacco, spices and condiments chiefly turmeric are the main non-food crops of the districts. Sugarcane is the one of the most important cash crops of the districts. The area sown under it is on the increase in the both the districts, particularly since the forties of the last century. In Kheri district, from 33,590 ha in 1939-40, it came to occupy 80,452 ha in 1972-73, and increased significantly to cover 2, 24,036 ha area in 2002-03 (Table 2.10). Similar is the case with Bahraich district (Table 2.9).

Irrigation: Both the districts are well provided with means of irrigation which is obtained mainly from wells, tanks, and canal. Owing to the generally abundant rainfall, there is comparative less need of irrigation in these districts. In the period preceding the attainment of independence by country, the only major irrigation work undertaken was the construction of the Sarda Canal which was completed in 1929 and Kheri district was one of those districts which have been benefited by it. To augment the capacity of the canals, especially during the years of drought, the ‘Sarda Sahayak Project’ was taken up in 1968. The 260 km long feeder channel of it emerged from the banks of the Sharda River. It provides canal irrigation to 16 districts of central and eastern Uttar Pradesh. It includes Girijapuri barrage on Girwa River in KAT. The project was completed in 2000.

(d) Other occupation and biotic pressure

Other source of income is large and small scale industrial units. Among large scale units, there are four sugar mills located at Palia, Gola, Lakhimpur, and Belraya. The Bajaj Hindustan Limited is the prominent one. The common problem faced by both DNP and KAT is enormous biotic pressure in term of illegal collection of forest resources and livestock grazing, and anti social elements from across the international border. This has affected the corridor in between forests of both countries critical for animal movements.

2.8 Review of Literature

An overview on the status of research and monitoring in protected areas of the Indian *Terai* has been provided by Mathur (2000). This brief review highlights past surveys, biological studies, and ecological assessments – floristics and faunal studies, and land use and socio-economic studies. The overview identified important gaps, research needs, and priority research issues. Similarly, Peet *et al*. (2000) highlighted significance of *Terai* grasslands in Nepal and reviewed recent researches and presented future priorities. Richard *et al.* (2000) has edited several technical and status papers relevant to tall grasslands in Nepal and collectively these papers provide an insight on grasslands in Nepal, management practices, and ecology of associated fauna. Besides these documents, no other single comprehensible research synthesis or a review exists about *Terai*. However, as stated earlier the Indian *Terai* forms a major part of Terai- Duar Savanna and Grasslands, an ecoregion (Olson and Dinerstein, 1998 and 2002). Dinerstein *et al.* (1997) has recognized the Indian sub-continent as the prime bioregion for the long term conservation of tigers and identified 11 Level 1 Tiger conservation Units (TCU), 7 Level II TCUs, and 37 Level III TCUs. The WWF-International identified the Terai Arc Landscape (TAL) as one of the three priority landscape in the Indian sub-continent for immediate conservation attention to save wild tigers (WWF, 2000). In response to this, Johnsingh *et al.* (2004) carried out a short term rapid assessment on the status of tiger and associated species in TAL on the Indian side (ca. 42,700 sq km) having ca 15,000 sq km of forest area. The study in such a vast area revealed that the tiger populations are distributed in nine disjunct forest blocks (named them as Tiger Habitat Blocks, THB) and identified over 10 corridors or connectivity potential enabling movement of tigers between the sub-populations. Three constituent forest fragments/PAs included in the Dudhwa landscape constitute three THBs.

A review on the status, distribution, ecology, conservation issues, and researches on the Ungulates of the Indian *Terai* (i.e. rhino, wild buffalo, nilgai, sambar, swamp deer, hog deer, cheetal, barking deer, and wild pig) has been recently provided in the 'Ungulates of India' (Sankar and Goyal, 2004). The 'Important Bird Areas – Priority sites for conservation by Islam and Rahmani (2004) is probably the most comprehensive and an updated review of 'sites of international importance for the conservation of birds and their habitats'. This important illustrative document included a detailed account on each IBA in the Gangetic Plain and the state of Uttar Pradesh and highlights status, distribution, and available research information on 3 critically endangered, 3 endangered, and 19 vulnerable birds relevant to this biogeographic zone and also to the study area. Practically, this document describes all important grassland, wetland (marsh, swamp) sites in the Indian *Terai* and draws attention towards birds of conservation concern.

Three main constituent PAs of the Dudhwa landscape were carved out from managed forests under the control of State Forest Department, U.P. Thus, primary source of information about DNP, KWS, and KAT comes from the old documentation of the Department in the form of Forest Working Plans. The Forest Working Plans of North and South Kheri Forest Divisions are of relevance in case of DNP and KWS respectively. While plans of Motipur and Dharmapur Forest Reserves in Bahraich district are of direct relevance to KAT.

Kanjilal (1993) provided a 'Flora of Pilibhit, Oudh, Gorakhpur and Bundelkhand' in early 1940s. The areas of Dudhwa landscape lies in the earswhile Oudh region. This was followed by pioneer work on forest types of India by Champion (1936) and Champion and Seth (1968) also describing forest types for the landscape. The Forest Working Plan officers adopted this valuable classification for planning and management of forests. Whyte (1964) described the grasslands in the country in the four agricultural zones, mostly giving their composition and some agronomic aspects. Thus, this reference is of significance in the present context. Subsequently, Dabadghao and Shankarnarayan (1973) provided grass cover types of India based on data from 507 field sites across the country. The *Phragmites-Saccharum-Imperata* grass cover types and its description are relevant to the landscape. Mathur *et al*. (2003) in the review on '*Terai* grasslands – diversity, management and conservation perspective' summarized researches on tall grasslands in India and Nepal, described diversity and management practices across the vast *Terai* region, and highlighted the future perspective. Panigrahi *et al.* (1971) made contribution to the Botany of *Terai* forests of Uttar Pradesh and added to the knowledge of floristics. Hajra and Shukla (1982) examined the botanical aspects of proposed new habitat for rhino in DNP and compared with the floristics of Kaziranga National Park, Assam. Rodgers and Panwar (1988) stressed the significance of DNP, KWS, and KAT and their importance for long term conservation so as to safeguard representative biodiversity of the Upper Gangetic Plain biotic province. Singh (1997) provided flora of DNP and described 821 plants from DNP and adjacent lands in Kheri district.

Kumar (2002) carried out the first time systematic studies on vegetation i.e. the structure and composition of forests and grasslands in DNP, KWS and adjacent managed forests of NKFD and SKFD. Based on extensive sampling, he described a plant diversity of 259 species belonging to 199 genera and 76 families. He also described diversity in Upland and Lowland grasslands and grassland succession.

Faunal surveys and research studies oriented towards conservation of species of concern or a threatened species were also initiated concurrently long time ago and such efforts are being continued (Mathur, 2000). Important once are: Blanford (1888)**,** Baker (1906, 1912, 1921)**,** Schaller (1967), Spillet (1967), Ali and Rilpley (1969), Daniel (1980), Inskipp and Inskipp (1983), Oliver (1984 and 1985**),** Singh *et al.* (1986 and 1990), Bell (1986), Rahmani (1996, 2001), Whitaker and Whitaker (1989), Sankaran and Rahmani (1990), Sankaran (1991), Qureshi *et al.* (1991), Rahmani *et al.* (1991), Bell and Oliver (1992), Sinha and Sawarkar (1991), Sinha and Singh (1994)**,** Javed (1996), Javed and Rahmani (1998), Javed *et al.* (1999), Qureshi *et al.* (2004), Sinha and Sinha (2007), Uniyal and Hore (2008), Hore and Uniyal (2008). One can find important references on habitats, swamp deer, and tiger in DNP and KWS during the period of 1960s in the incredible research work on the Indian wildlife by Schaller (1967).

Full time researches in past two decades or so and based in DNP and other areas of the landscape have contributed eight Ph.D. theses. They deal with: flora of Dudhwa (Singh, 1978), ecology of swamp deer (Singh, 1984), ecology of wild animals and socioeconomics of local people in DNP (Singh, 2002), bird assemblages and community structure (Javed, 1996), breeding behaviour of Bengal florican (Sankaran, 1991), ecology of black necked stork (Maheshwaran, 1998), and ecological assessment of forest spatial heterogeneity, species diversity, and grassland burning practices (Kumar, 2002).

Despite changes in land use during 5-7 decades and rapid transformation of the entire landscape, only a few isolated studies have been made on changes in land use and mapping of land cover based on remote sensing. The first such effort was by the Remote Sensing Application Centre (RSAC), Lucknow, Uttar Pradesh in early 1990s. Satellite data of Landsat-3 passed on

November, 10, 1981 was used for assessing land cover types in DNP (Singh, 1985, Sankaran, 1989). The Indian Institute of Remote Sensing, Dehradun also conduced a short term study on ‘forest type mapping of DNP using IRS - 1B LISS II (36.5 m resolution) satellite data of January, 1994 and provided information on 11 land use/cover types categories in core and buffer area of DNP on the basis of each forest range/ block wise (Kumar, 1996). Later, Kumar *et al.* (2002) described 17 land use/cover categories in a larger landscape units named as the ‘Terai Conservation Area’. TCA included DNP, KWS, forests of NKFD, SKFD, and vast agricultural matrix. They also used IRS 1B LISS II data but of January, 1997 and highlighted characteristic spatial patterns in TCA. This study also made use of software FRAGSTAT ARC version 3.02 for quantifying landscape structure and spatial distribution of patches. Johnsingh *et al.* (2004) used IRS 1B LISS III (23.5 m resolution) data for TAL and provided insight on the distribution and status of tiger and large ungulates in three Tiger Habitat Blocks relevant to the present study area and the status of potential connecting areas between them. Kharel *et al.* (2002) mapped corridor between Royal Bardia National Park in Nepal and KAT, India by using GIS. Sinha *et al.* (2003) assessed the corridor viability and habitat restoration between DNP and KAT and its management in western *Terai*. Based on the most recent exercise on the monitoring and assessment of status of tigers, co-predators and prey in 17 tiger range states in India, Jhala *et al.* (2008) described that the major population of tiger in the state of U.P. is constituted by DNP, KWS, KAT and forests of Pilibhit, NKFD, SKFD. The forested area with tiger occupancy constituted by this population is 1,916 sq km. This population is connected across the Nepal border *via* the forests of Pilibhit (Lagga-Bagga) to Sukla Phanta of Nepal and KAT is connected across the border to Bardia Ntaional Park in Nepal.

Sharma (1991) carried out land use survey in Tarai tract focusing on the eastern U.P. and provided detailed account of changes in land use and cropping pattern. In recent years, the State Forest Department and PA management using the participatory rural appraisal (PRA) techniques carried out micro-planning and generated valuable information on villages within PAs and on periphery. Information provided is mainly related to demography, socio-economics, occupation, land use, resource dependence and conservation issues. Chauhan (2005) examined the pertinent management issue of man-wildlife conflict in and around DNP and KAT and provided an insight on human causalities by tiger in KAT and livestock depredation by tiger in and around DNP and suggested management strategies.

Mathur (2000) in his review on the status of research in *Terai* identified few future research needs. These needs are: (a) understand floodplain dynamics, (b) decide grassland burning/management regimes, (c) update information on the status and ecology of threatened species and rapid land use changes, (d) evolve strategies for weed management, (e) understand metapopulation dynamics and genetic exchange, and (f) assess resource dependence, man-wildlife conflict, and develop mitigation strategies. In short, action oriented research can not be over-emphasised and there is an urgency to blend research monitoring, and management by adopting adaptive management approach

The present study is in response to the above requirements and aimed to address select themes.

Chapter 3

The Landscape – Land Use and Land Cover

3.1 Introduction

Land information is important to a wide variety of human activities such as agriculture, forestry, water resources, as well as other type of land resources management (Ghiassi *et al.*, 1997). Sustainable management of natural forests has been a worldwide issue as forest resources are important socially, economically and environmentally, especially tropical forests which are home to atleast two-third of the world organisms (UNCED, 1992; Hussin *et al.*, 1996; Dahal *et al.*, 2002). Human activities now affect most living resources and are increasing in intensity and extent. The accelerated rate of deforestation, forest fragmentation, and forest degradation is not only a threat to the continuous supply of forest products for the livelihood of local people but it also has many adverse consequences on a regional and global scale. The need to be able to detect and predict changes in the natural environment has never been greater. The traditional field ecological data do not translate readily to regional or global extents, and models derived purely from such local data are unlikely to predict the global consequences of human activities. The implications of ecological analysis though extend well beyond the local scale, and there is considerable need for, and increasing interest, in ecological investigation at wider spatial scales, from the landscape to the entire globe (Gulinck *et al*., 2000; Los *et al.*, 2002; Kerr and Ostrovsky, 2003; Aplin, 2004). Consequently, remote sensing has emerged as an important tool in ecological investigations, providing the only realistic, cost-effective means of acquiring data over large areas (Nagendra, 2001; Kerr and Ostrovsky, 2003).

Over the past decades, tremendous progress has been made in demonstrating the potentials and limitations of the applications of remote sensing in forestry. Remote sensing is a powerful technique for surveying, mapping, and monitoring earth resources. This technology combined with Geographic Information System (GIS) which excels in storage, manipulation, and analysis for geographic information and socio-economic data provides a wider application. Land resources and environmental decision makers require quantitative information on the spatial distribution of land use types and their conditions as well as temporal changes (Mendis and Wadigamangawa, 1996; Bilbisi and Tateishi, 2002; Sharma, 2002).

3.1.1 Land Use and Land Cover

Land use refers to "man's activities and various uses, which are carried on land (such as agriculture, settlements, industry etc)". Land cover refers to the material present e.g. vegetation, water bodies, rocks/soil and other resulting from land transformation (Chaudhary *et al*., 2008). Although land use is generally inferred based on the cover, yet both the terms – land use and land cover being closely related are interchangeable. It is necessary to have accurate information about present land use/land cover so as to prepare integrated plans for optimal utilization of natural resources in the region. Mapping land use/land cover (LULC) changes at regional scales is also vital for a wide range of applications in different disciplines. LULC alterations (based especially on human activities), negatively effects the patterns of climate, biodiversity, and even a species as it may limit its distribution (Kerr and Ostrovsky, 2003; Reis, 2008). Land-use is the most direct and leading driving factor to the land cover change (Chenghu and Jiancheng, 1999). Land use/Land cover, being the new concept developing with the advent the remote sensing technology and two different concepts are of utmost significance. The applications of remote sensing techniques are well established in land use/land cover studies (Anderson, 1971, Anderson *et al*., 1976, Sinha *et al.*, 1989, Hooda *et al*., 1992, Kushwaha and Oesten, 1995, Ram and Singh, 1995, Toleti, 1995, Hussin and Shaker, 1995, Clevers *et al*., 1999, Chaudhary, 2003, Chaudhary *et al*., 2008). Satellite remote sensing can be used to estimate the variety, type, and extent of land cover throughout a study region, meeting a fundamental need that is common to several ecological applications. Information on spatial spread and monitoring the dynamics of the land use/land cover is a basic prerequisite for planning and implementing various developmental activities. The new technology of high resolution satellite imagery (<10 m) demonstrated its metric potential for mapping and has a wide resource management potential.

3.1.2 Remote Sensing and Forest Ecology

Remote Sensing technique offers unparalleled technique to monitor urban, green, and non-green land changes at regional and local scales from space (Bilbisi and Tateishi, 2002). Vegetation cover in general and forest cover in particular are indicators for the quality of the environment. The methods of vegetation and forest cover classification have progressed in recent years (Duong *et al.*, 1999).

Satellite remote sensing data has been used in India and elsewhere since past two decades or so in specified areas with limited application. Forestry sector is one of the main application areas where this technology has been used from the beginning (Porwal and Roy, 1982; Porwal and Pant, 1989; Roy *et al*., 1985). Remote sensing technology opens both the opportunity and challenges in the forestry sector. Satellite data has been used to obtain the forest cover, forest cover change, and other forest statistics information combined with forest inventory data. Other application areas are wildlife habitat mapping, soil and watershed management and various researches (Kamat and Panwar, 1986; Roy *et al*., 1986). The importance of satellite data in the country has been well recognised and increasingly different sectors within the ambit of environmental/natural resource management are making its optimum use. According to Kerr and Ostrovsky (2003), remote sensing generates a remarkable array of ecologically valuable measurements which includes the details of habitats (land cover classification) and their biophysical properties (integrated ecosystem measurement) as well as the capacity to detect natural and human induced changes within and across landscapes (change detection).

3.1.3 High Spatial Resolution Imagery

Remote sensing has made an enormous progress over the decades and a variety of sensors now delivers medium and high resolution data on an operational basis (Hussin, 1999; Clark *et al*., 2004). Use of satellite imagery for natural resources development has come a long way after the launch of first American satellite Earth Resource Technology Satellite (ERTC), now known as Landsat-1 in the year 1972. Subsequently, a number of satellites have been launched from different countries with improved spatial, spectral, radiometric, and temporal resolutions for the development of natural resources throughout the world.

New spaceborne systems with very high spatial resolutions and multispectral sensors are now available from commercial sources and they improve ability to resolve objects at spatial scales previously only attainable from aerial photography or classified satellite imagery. They are: IKONOS-4 m; Quickbird-2.4 to 2.8 m; and panchromatic-1 m and 0.6-0.8 m. At these resolutions, direct identification of certain species (e.g. through the detection of individual tree crowns) and species assemblages is becoming feasible (Turner *et al*., 2003). Today, India has an impressive array of remote sensing satellites meeting the national need for management of natural resources. These satellites with spatial resolution range from 360 m to better than 1 m and also with panchromatic and multispectral imaging capability.

Above new generation of satellites with improved temporal frequency of data acquisition, better spatial, spectral resolution has considerably enhanced the potential of remote sensing in development of spatial information. It enables more detailed assessment of vegetation, allows identification of important smaller patches in an environmentally gradient environment, and is also considered helpful in evaluation of impacts on biodiversity of specific management policies (Innes and Koch, 1998; Mahito and Takeshi, 1998). It also aid in locating boundaries accurately and rapidly and the amount of time, energy, and funds saved thereby is great and maps are much more reliable.

Improved spatial resolution allows textural identification of ground features whereas the coarse resolution images are difficult to use without the knowledge of ground features. The likelihood of 'pure' pixels being collected for specific land cover types increases with finer spatial resolution (O'Hara, 2002). Due to clarity for feature extraction, the high spatial resolution images require lesser supervision, provide more operator ease, reduce instances of misinterpretation, and provide higher speed in interaction–cum–delineation. The high resolution data allows map to be produced at fine scale which give clear identifiable information of forest type, physical infrastructure, and boundaries. Assessment on finer scale enables both detailed assessment of structure elements between – habitat, landscape, or regional scale, and the assessment of structural elements describing within habitat diversity (Innes and Koch, 1998). Thus, the availability of high resolution satellite imagery now makes it possible to perform accurate mapping and more precise modelling and planning process. It is generally believed that high resolution data would always provide a better interpretation and delineation of boundaries of diverse land cover categories easily. However, it is not always true from the point of view of varied level of planning processes being carried out in the developing countries.

High resolution imaging from space has seen a steady growth with an improvement of one order resolution once in thirteen years over the last three decades (Kumar, 2007). NOAA-A/Landsat-1 satellite launched in 1972 paved the way for much better satellite sensors with greater spatial and spectral resolution. SPOT family of five satellites with one launched in April 2002 has helped in developing the commercial market for space imagery of the Earth. The Indian Remote Sensing (IRS) family of 10 satellites started in 1988 with IRS–1A with a spatial resolution of 72 m, improved the spatial resolution to 5 m with IRS–1C in 1995. Till the launch of IKONOS (1 m) in 1999, this was the highest spatial resolution data available in civilian domain. Finally, India has added yet another satellite i.e. Cartosat - 2 with a spatial resolution of better than 1 m in January, 2007.

One of the high resolution satellites in the family of IRS is IRS P-6, also known as Resourcesat–1. It was launched into polar orbit on 17 October, 2003 from Satish Dhawan Space Centre by the Indian PSLV C5. Data from one of its high resolution sensor i.e. Linear Imaging Self Scanner IV (LISS IV) with spatial resolution of 5.8 m has been used in different sector of resource management. A few studies in India have evaluated the capability of LISS IV in different fields (landslide damage assessment - Kumar and Martha, 2004; urban land use/cover – Ramesh *et al*., 2004; estimation of water spread area – Shanker 2004; studies on glaciers – Kulkarani, 2007; coastal zone studies – Bahaguna, 2004 and Rajankar *et al*., 2004; agriculture application – Shesha Sai *et al*., 2004 and Oza *et al*., 2004; developmental planning – Singh, 2004; and forest management – Sudhakar *et al*., 2004).

Studies are yet to be conducted to evaluate the potential of LISS IV for resource mapping in the context of protected areas and its implications for improved PA management. Often natural resource managers need finer detailed land use maps at such scale which has high communication value, accuracy and which can be readily interpretable for planning and formulation of management strategies. Present study thus attempted to utilize capability of fine resolution data provided by the Indian satellite, IRS P-6 LISS IV to develop land use/land cover maps at the scale of 1:25,000 for Dudhwa landscape and to examine its potential benefits and limitations in natural resource mapping over earlier medium resolution satellite data.

3.2 The Objectives

In light of above background, objectives of present investigations were:

- Assess land use/land cover for Dudhwa landscape and describe landscape spatial patterns.

- Assess the potential of LISS IV for improved natural resource mapping and in meeting information need of planning and management.

3.3 Methodology

The methodology used for the assessment of land use/land cover in Dudhwa landscape and evaluation of effectiveness of high resolution satellite data for improved natural resources mapping is described below:

3.3.1 Land Use/Land Cover Mapping

Procedure for preparation of land use/land cover maps for Dudhwa landscape using LISS IV included the following four steps:

a) Data acquisition and image processing
b) Land use/land cover classification
c) Land use/land cover mapping
d) Accuracy assessment

(a) Data acquisition and image processing

The digital data of IRS P-6 LISS IV data was used in the present study. It operates in three bands in the visible and near infrared region (VNIR) and has 5.8 m spatial resolution and five day revisit capability. Its specifications are given in Table 3.1.

Table 3.1 - Specifications of LISS IV Sensor of IRS P-6

Specification	LISS IV
Spectral bands	0.52 - 0.59 (Green) 0.62 - 0.68 (Red) 0.77 - 0.86 (NIR)
Spatial resolution	5.8 m at nadir
Swath	23 km
Quantisation	7 bits

The eleven scenes of early and late winter (October to March) acquired in the year 2004 and 2005 covering the three protected areas and their peripheral areas were procured from the National Remote Sensing Agency, Hyderabad (Table 3.2; Fig. 3.1). The data sets were imported into ERDAS image processing software to create False Colour Composite (FCC). Radiometric and geometric corrections were carried out on it and the study area was extracted using boundaries of DNP, KWS, and KAT. To improve the image, 3 $\times$ 3 low pass filter was applied. This contrast enhancement decreased the spatial frequency of pixel and made it more homogenous (Lillesand and Kiefer, 2000). Digital data was enhanced and maps were generated for ground validation and field data collection.

Table 3.2 - Detail of the IRS P-6 LISS IV Data Used for Land Use/Land Cover Mapping of Protected Areas in Dudhwa Landscape

Path	Row	Date	Area
102	46	25 October, 2005	DNP
102	47	3 December, 2004	DNP
102	49	14 November, 2004	KAT
102	49	19 November, 2004	KAT
102	50	19 November, 2004	KAT
201	64	9 March, 2004	DNP
201	65	9 March, 2004	DNP
201	66	14 February, 2004	DNP
201	66	9 March, 2004	KWS
201	67	14 February, 2004	KWS
201	68	14 February, 2004	KWS

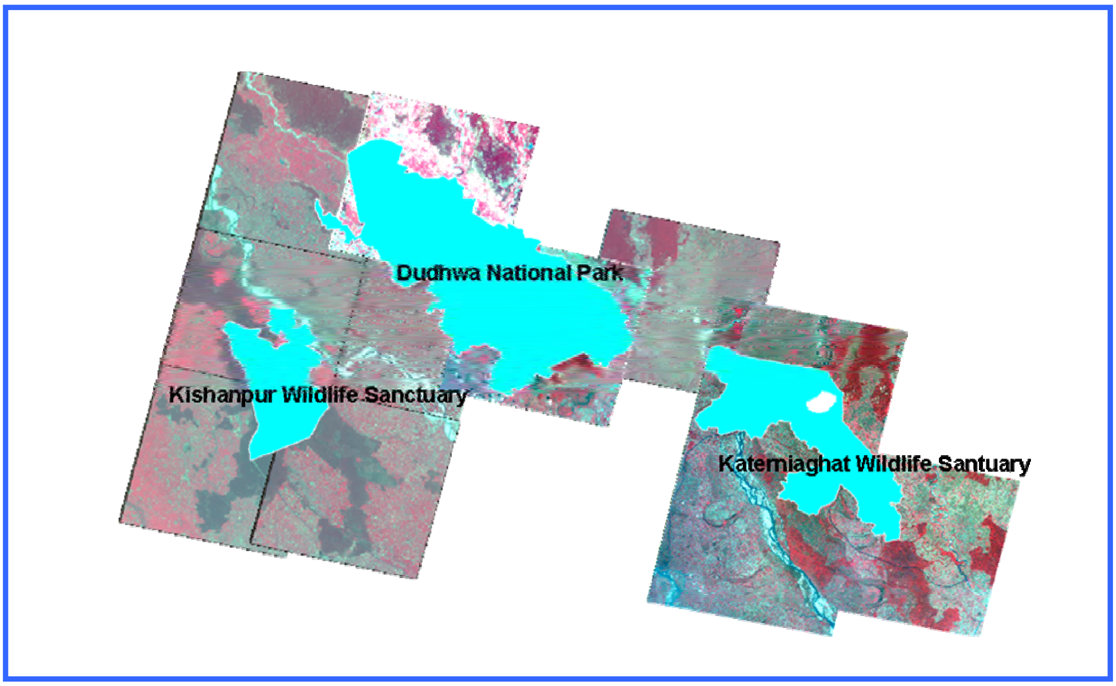


Fig. 3.1 - The Images of IRS P-6 LISS IV Covering Dudhwa Landscape

(b) Land use/land cover classification

Field sampling: Reconnaissance of the area was done in March, 2005 to get acquainted with the general patterns of land uses in the area. FCC was used in the planning and implementation of survey. Before sampling, different tones and textures were marked on enhanced FCC to increase the efficiency of survey. These markings were checked during field survey and their geographical coordinates were recorded using GPS instrument. Coordinates of predominant land use/land cover types and few prime localities, and characteristics vegetation types were also recorded.

After the field survey, out of vast area of Dudhwa landscape, KAT was chosen as representative site for maximum field sampling as no previous information on this constituent area was available. For DNP and KWS, land use maps prepared by Kumar *et al.* (2002) were also used as base maps for mapping.

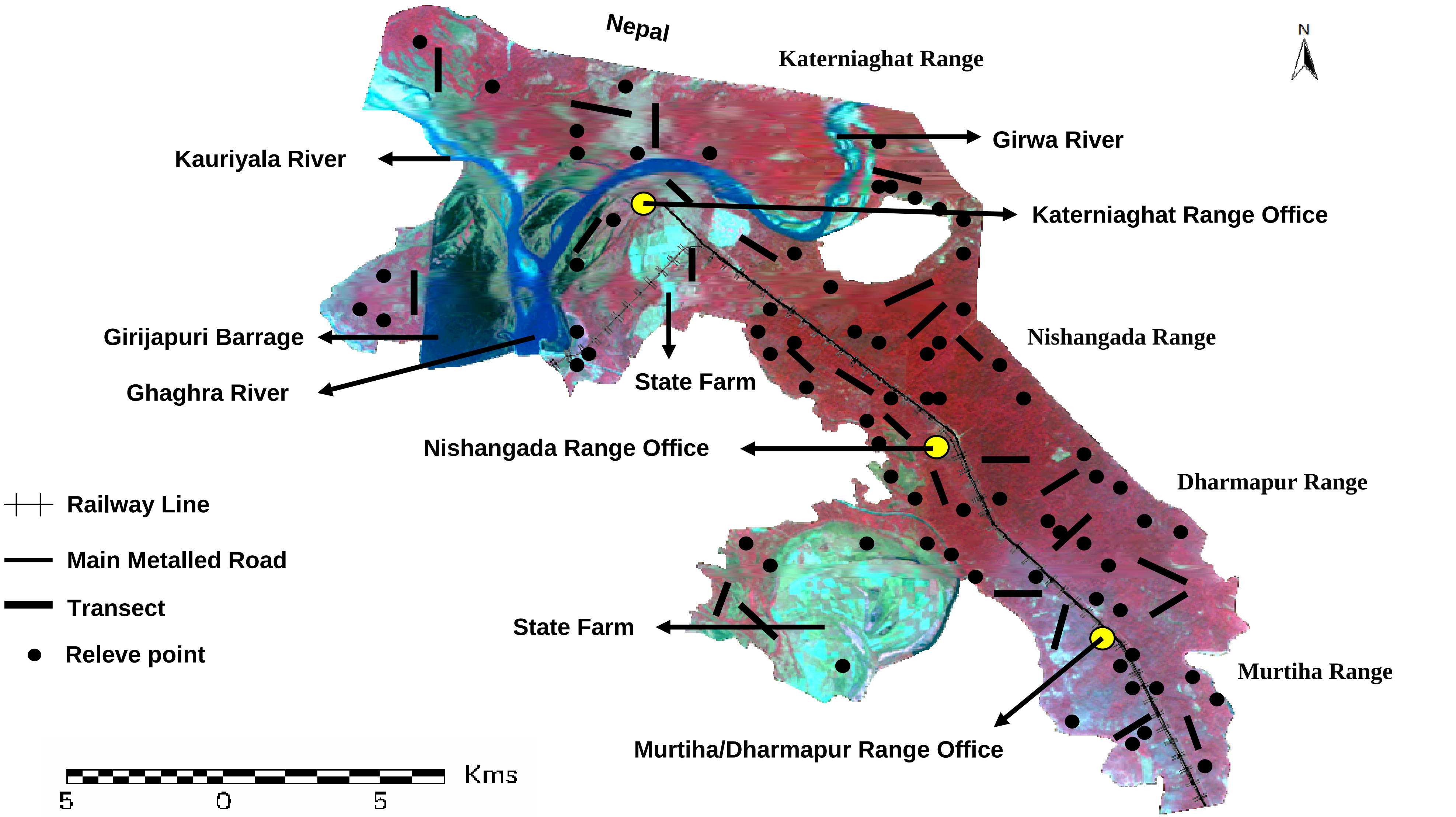
Further, extensive field sampling was performed in KAT by laying sample plots. Plots were distributed on the basis of pre-classified land use/land cover map prepared after the reconnaissance. The second stratification was made on the basis of one of the smaller unit of management i.e. beat. Transect of 2 - 2.5 km length was established on the ground in each beat (Fig. 3.2)**.** Along each transect, circular sampling plots of 10 m radius were laid at 250 m fixed interval. In addition to sampling plots on transects, few Releve sample plots were also laid to confirm the vegetation types where the problem of correlation with satellite data arose during interpretation. At each sample plot, dominant vegetation type, geographical coordinates, and canopy density using a densitometer was noted. In addition, individuals with >30 cm girth at breast height (GBH) and >3 m height were considered as trees and their number and species were enumerated (Mueller-Dombois and Ellenberg, 1974). Altogether, 27 transects were established and in total, 505 sample plots (218 on transects and 287 as Releve) were laid in KAT during a period of 2 years of field work (2005 and 2006). The land use maps by Kumar *et al.*, (2002) were appraised by laying 310 and 51 sample plots in DNP and KWS, respectively.

Image interpretation**:** The development of an accurate, detailed land use/land cover map in GIS format requires interpretation of image to identify and delineate land use/land cover classes (Welch *et al*., 2002). The ground validation information was then used to prepare interpretation key for delineation of different land use/land cover classes (Table 3.3). Plates 3.1 to 3.4 represent few examples of image recognition pattern used for classifying.

Land use/land cover classification**:** For forested landscapes in India, the most accepted classification of forest types is that of Champion and Seth (1968). It is primarily a climatic and edaphic classification with ecological information and floristic composition. The classification scheme does not contain the level of details provided by LISS IV data, thus a new classification scheme was adopted. Forest classification was developed using PC-ORD software for performing hierarchical cluster analysis using Ward's cluster method and Euclidean distance interval (McCune and Grace, 2002).

Some of the forest types recognised on satellite imagery were found to have 1:1 relation with vegetation communities derived after cluster analysis of the

Fig. 3.2 – IRS P-6 LISS IV Image Showing Prominent Locations and Position of Transects and Releve Plots Laid in KAT



field data but few did not match. It was observed that few forest types were being represented by two or three vegetation communities or *vice-versa*. The reasons could be attributed to variations within a community either due to variable canopy closure or difference in the month of satellite data and sampling which affects the spectral signature in the satellite data and cause misinterpretation. To properly come out with a valuable forest types, few vegetation communities and forest types were regrouped so that a 1:1 relation existed.

Field data analysis**:** The collected field data was analyzed for computing the density of prominent tree species following methods of Kent and Cooker (1992).

The following formula was used for density calculation:

$$\textbf{Density} = \frac{\text{Total number of individuals of a species in all plots}}{\text{Total area of all plots (ha)}}$$

(c) Land use/land cover mapping

Based on the developed interpretation key and image recognition elements, on-screen visual interpretation was performed on the digital imagery. This interpretation consists of marking the boundaries of areas representing single cover units on the image using on screen digitization to assign nomenclature heading, as well as extrapolating the established delineation and identification of different parts showing similar characteristics (Faour and Kheir, 2002). The working scale (display of image, identification of features and digitizing) was set at 1: 12,500 scale to allow a finer presentation of existing map at 1: 25,000. ERDAS Software version 8.7 was used to prepare the land use/land cover map and attribute of polygons were given in Arc View 3.2.

Table 3.3 - Interpretation Key for Delineation of Land Use/Land Cover Classes from IRS P-6 LISS IV in Dudhwa Landscape

S.No.	Tone	Texture	Pattern	Physiography	Land Use/Land Cover classes
1	Dark Red	Smooth	Regular	On old alluvial upland area	Dense Sal Forest
2	Dark to medium red	Smooth to medium	Regular to irregular	Occurs alongside Dense Sal	Moderately Dense Sal Forest
3	Red with blackish tinge	Coarse	Irregular	Occurs on gentle slope, old river terraces, peripheral area	Sal Mixed Forest
4	Medium Red with blackish tinge	Medium to coarse	Irregular	Lowland area, old river terraces, peripheral area	Open Sal Forest
5	Dark brown	Coarse	Regular	Occurred as interspersed patches in grassland	*Chandar* Sal Forest
6	Red	Coarse	Irregular	Along streams, river, wet depression	Tropical Semi-Evergreen Forest
7	Bright red	Medium to coarse	Irregular	Along perennial river	Tropical Seasonal Swamp Forest
8	Brownish Red	Coarse	Irregular	Upland area, peripheral adjoining river	Mixed Deciduous Forest
9	Blackish Red	Coarse	Irregular	With Moderately Dense Sal	*Terminalia alata* Forest
10	White	Coarse	Irregular	Occurs on dry clayey soil, on ground higher than surrounding area and river bed	*Aegle* Forest
11	Light brown	Medium to coarse	Regular & Irregular	On new sandy deposits of river and stream	Khair and Shisham Forest
12	Dull red with greenish tinge	Medium to coarse	Regular	Along road, railway line	Teak Plantation
13	Dull yellow to dull red with black tinge	Medium to coarse	Irregular	Along road, railway line, villages, in grassy blank, and clear felled Sal	Other Plantations
14	Greenish yellow	Medium	Regular	Upland area	Upland Grassland
15	Light to Dark bluish green	Medium	Regular	Lowland area and along river and streams	Lowland Grassland
16	Dark to light blue	Fine	Regular	Natural course of perennial rivers and canal	River
17	Greenish blue	Fine	Regular	In depression and low lying areas	Swamps and water bodies
18	Yellow to red	Coarse	Irregular	River islands	Scrub
19	Bright red; greenish blue	Coarse	Regular	Village, in regular geometrical shapes	Agriculture
20	White	Fine	Regular	Along the bank of river	Sand Bar
21	Pinkish	Fine	Regular	Near habitation	Fallow Land

Based on the experience of interpretation of satellite imagery for KAT, similar interpretation key was used for DNP and KWS. In case of DNP, similar to KAT, visual interpretation technique was applied, and to expedite the preparation of land use map for KWS, unsupervised classification technique was used.

(d) Accuracy assessment

The accuracy assessment estimates thematic errors in the data, providing users the information needed to assess data suitability for a particular application. Out of total sample plots, 200 sample plots were kept separate for accuracy assessment. The cover type information of the plots was compared with classified maps. The sample plots collected from DNP and KWS were also used for estimating accuracy. Overall accuracy and Kappa statistics were calculated using ERDAS 8.7 software (Joshi *et al.*, 2006).

3.3.2 Effectiveness of High Resolution Data (LISS IV) for Land Use Mapping

To assess the level of information in LISS IV and its efficacy for enhanced land use mapping, a qualitative and quantitative comparison of LISS IV with two medium resolution datasets i.e. Landsat ETM+ and LISS III was carried out. The approach used in this present context was similar to that of Faour and Kheir (2002) and Gupta and Jain (2005). The details of digital data of three datasets used in present investigation are presented in Table 3.4. The spatial resolution of three datasets varied from 5.8 m (LISS IV) to 30 m (Landsat ETM+). The evaluation consists of two parts. First, the qualitative assessment, which included the visual analysis of features on imagery to observe the level of sharpness, clarity, and reliability of information. The second part focused on quantitative assessment which involved the estimation of extent of the mapping in three datasets.

Table 3.4 - Datasets Used for Comparison of Information Content

Satellite and Sensor	Month and Year	Resolution (m)
Landsat ETM+	September, 1999	30
IRS 1D LISS III	October, 2001	23.5
IRS P-6 LISS IV	November, 2004	5.8

For comparison, a sample site (2260 ha) from KAT was selected (Fig. 3.3). All three datasets were georeferenced and the sample site was delineated from each dataset. Using visual interpretation, four categories were extracted from images for quantitative comparison. The categories included: main road, forest road, railway line, and vegetation types. For the first three features, length was measured and compared for three datasets and for the last category, only comparison between LISS IV and LISS III was performed and 'concordance area' i.e. area of vegetation type classified correctly by both the datasets was estimated.

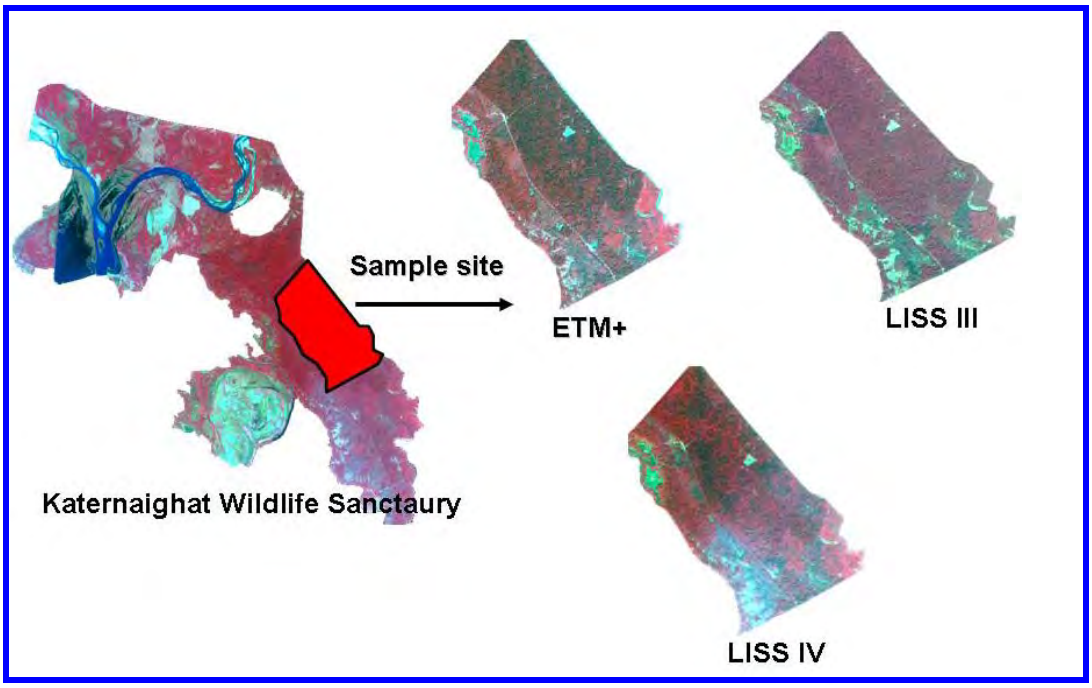


Fig. 3.3 - Images of the Sample Sites Extracted from Landsat ETM+, IRS ID LISS III, and IRS P-6 LISS IV for Quantitative Assessment

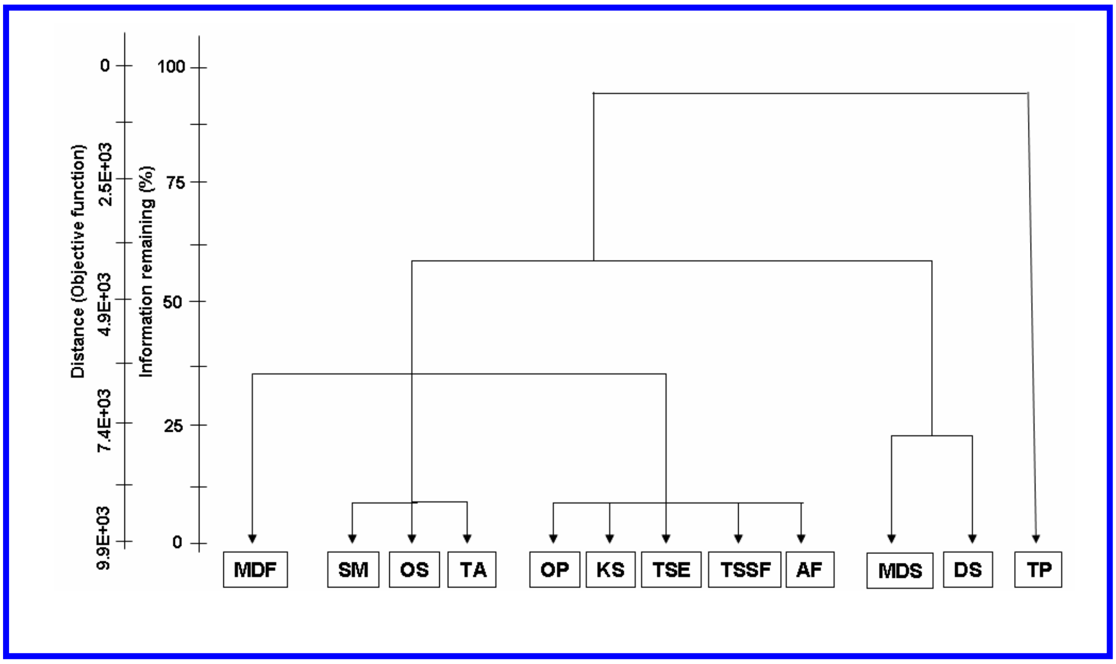
3.4 Results

The following section presents results on land use/land cover mapping and the evaluation of effectiveness of high resolution satellite data for the mapping purpose.

3.4.1 Land Use/Land Cover Mapping

The land use/land cover analysis revealed that Dudhwa landscape represents three larger disjunct forest fragments along with smaller, scattered forest fragments in human altered landscape. The mapping in three larger fragments/constituent areas using LISS IV allowed delineation of 21 land use/land cover classes. This included 14 forest types, two grassland types, three wetland types, and two other land use/land cover classes. Forest classes generated were supported by the cluster analysis resulting into 12 forest associations as shown in a dendrogram (Fig. 3.4). In cluster analysis, the Teak plantations were distinctly separated out in the first place. This was followed by a split in which two Sal dominated forest classes (Dense Sal Forest and Moderately Dense Sal Forest) made first cluster while the other split part broke up again and finally formed three new clusters. The largest cluster among these three clusters was constituted by Other Plantations, Tropical Semi-Evergreen Forest, Tropical Seasonal Swamp Forest, *Aegle* Forest, and Khair and Sissoo Forest. The second cluster was formed by three associations of *Terminalia alata* Forest, Open Sal Forest, and Sal Mixed Forest. The third cluster was made exclusively by Mixed Deciduous Forest.

Details of land use/land cover types are described in a sequence of KAT, DNP, KWS, and for entire landscape as KAT was selected for maximum field sampling. In addition, a comparison of three PAs (constituent areas) are presented below.



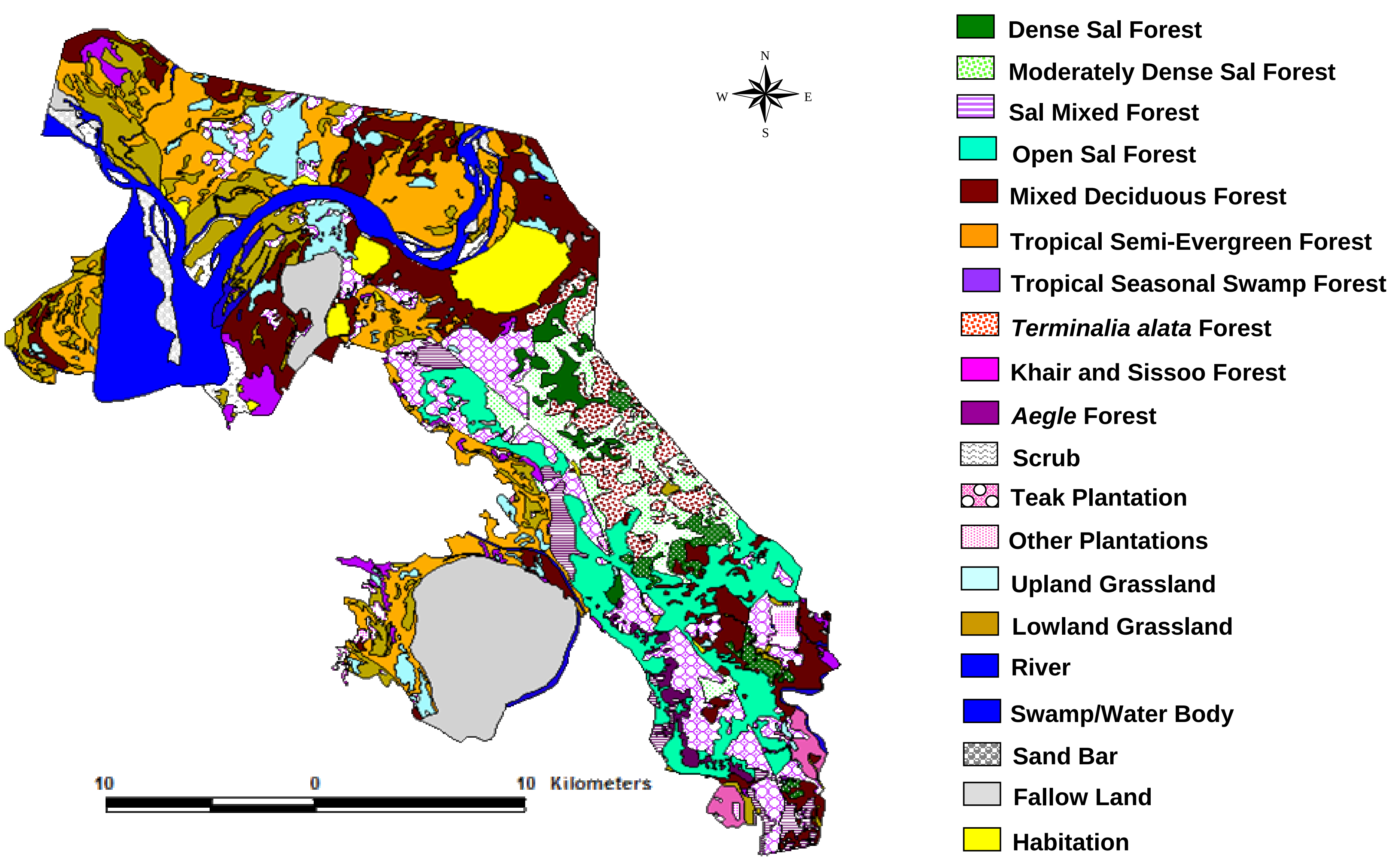
DS: Dense Sal Forest; MDS: Moder ately Dense Sal Forest; SM: Sal Mixed Forest; OS: Open Sal Forest; MDF: Mixed Deciduous F orest; TSE: Tropical Semi-Evergreen Forest; TSSF: Tropical Seasonal Swamp Forest; TA: Terminalia alata Forest; KS: Khair and Sissoo Forest; AF: Aegle Forest; TP: Teak Plantation; OP: Other Plantations

Fig. 3.4 - Dendrogram Showing Finalized Different Forest Associations in KAT

(a) Land use/land cover in KAT

The land use/land cover map developed for KAT is presented in Fig. 3.5 while land use classes, area, and per cent extent are represented in Table 3.5. Accordingly, different forests occupied 193.5 sq km or 48.3% of KAT. Besides this, plantations (Teak and others) covered 10.5% area of KAT. Among forests, Sal dominated forests under four different classes occupied 72.1 sq km or 18.0% of KAT. Four classes (Dense Sal, Moderately Dense Sal, Sal Mixed, and Open Sal Forests) were deciphered on the basis of cluster analysis and canopy. Accordingly, Sal dominated forests with >80% canopy owing to highest tree density (292 individuals/ha) and preponderance of Sal as a major species (199 individuals/ha) were designated as 'Dense Sal' Forest. The second class – 'Moderately Dense Sal' represented >60-80% canopy with moderate tree density value, being 252 individuals/ha and having representation of Sal to the extent of 106 individuals/ha. The third class was referred as 'Sal Mixed' Forest. In this case, canopy ranges between >40-60%

Fig. 3.5 - Land Use/Land Cover of KAT Developed from IRS P-6 LISS IV at the Scale of 1:25,000



and had overall tree density of 185 individuals/ha. Density of Sal in this forest class reduced to 71 individuals/ha. However, the top canopy was still having dominance of various co-associates of Sal. The fourth class was called as ‘Open Sal’ Forests having open canopy (<40%). This forest class still obtained high value of tree density, being 199 individuals/ha and maintained small proportion of Sal to the extent of 41 individuals/ha. The high value of tree density in this case was due to the fact that it had a presence of large number of middle storey trees of *Mallotus philippensis*.

Forests other than Sal dominated represented a substantial area (31.6%) of KAT. Seven different classes of Other Forests were recorded in KAT. The Tropical Semi-Evergreen Forest covered a significant area of KAT, being 12.48%. In addition to three important Other Forest classes of Mixed Deciduous Forest, Tropical Semi-Evergreen Forest, and Tropical Seasonal Swamp Forest, forest classes representing *Terminalia alata*, Khair and Sissoo, and *Aegle* dominated forests were also recorded in KAT. Two grassland types (Upland and Lowland) covered 47.4 sq km or 11.8% of KAT. Out of this, Lowland Grassland was conspicuous. Wetlands (Rivers, swamp, water bodies and even adjacent sand bar) represented 14.3% area of KAT. Among wetland, rivers were prominent in KAT as they covered a large area of 11.6%. Other land use/land cover classes included Fallow Land and Agriculture and they occupied 10.0% and 3.6% area, respectively. Details of the each land use/land cover classes are as follows:

Dense Sal Forest

This type of forest comprised of almost pure stand of Sal trees and occurred on well drained higher alluvial terraced (‘dammar’) with loamy soil. These forests were found in small patches on north-east side in Nishangada, Dharmapur and Murtiha forest ranges of the KAT (Fig. 3.2 and Fig. 3.5). Density of Sal was highest, being about 199 individuals/ha. The top storey besides Sal comprised *Terminalia alata*, *Syzygium cumini*, *Ehretia laevis*, and *Lagerstroemia parviflora*. These forests showed stratification with middle storey comprising *Mallotus philippensis*, *Madhuca longifolia*, and *Mitragyna* *parvifolia*. Undergrowth was also dense. The canopy density was high, being 80%. These forests covered 12.4 sq km or 3% of KAT area (Table 3.5).

At few places in Nishangada forest range, patches of pure stand of young Sal trees were noticed with no stratification and lesser undergrowth (Plate 3.1). Such forests patches were also merged in the class of Dense Sal Forest.

Moderately Dense Sal Forest

Moderately Dense Sal Forest was found alongside Dense Sal and occupied areas both in Nishangada and Dharmapur forest ranges (Fig. 3.2 and Fig. 3.5). Sal density in this class was medium, about 105.7 individuals/ha. Prominent species of these forests were *Mallotus philippensis*, *Terminalia alata*, *Syzygium cumini*, and *Litsea glutinosa*. Canopy density varied between 60% and 80 % and the class covered 5% area of the sanctuary (Table 3.5).

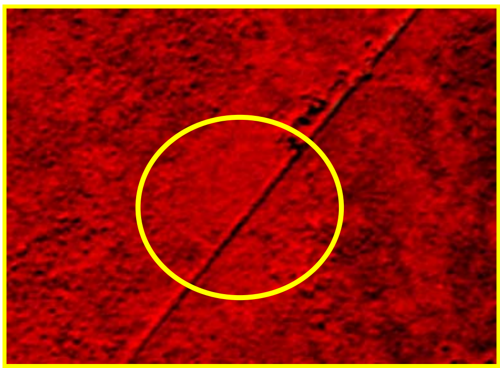
Sal Mixed Forest

This category of Sal forest occurred in lowland area on old river terraces and gentle slopes where soil was hard, dry, and impermeable stiff loam overlay pure sand. These forests were confined mostly along south-western boundry of the KAT (Fig. 3.5). This mixed category of Sal was generally found near grasslands and mixed deciduous forests and hereby got its characteristic association of other species, with being in good proportion with Sal. Density of Sal was low, being 71.1 individuals/ha and mostly were middle aged trees. Other dominant tree species were *Mitragyna parvifolia*, *Mallotus philippensis*, *Syzygium cumini*, *Haldinia cordifolia*, *Streblus asper*, and *Aegle marmelos*. The canopy density varied between 40% and 60% and the forest class covered 1.9% of KAT area (Table 3.5).

Open Sal Forest

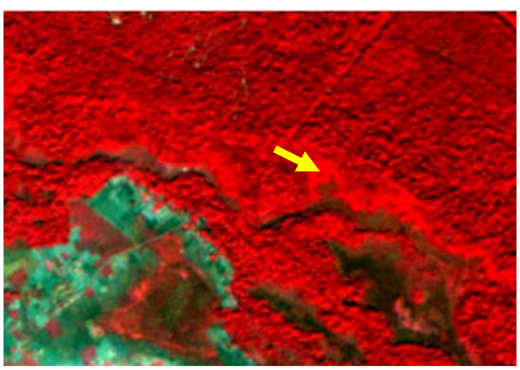
Open Sal Forest category of land use/land cover type had maximum area (7.9%) under occupance in KAT as compared to all other Sal forest classes

Plate 3.1 - Images of IRS P-6 LISS IV Showing Characteristic Image Recognition Patterns of Dense Sal Forest and Tropical Seasonal Swamp Forest in Dudhwa Landscape and their Corresponding Picture on Ground



IRS P6 LISS IV image on 1:12,500 scale **Nishangada range, KAT**

Dark red tone within circle represents the Dense Sal Forest in Dudhwa Landscape. The photograph on the right presents the Dense Sal Forest with poor ground flora and closed canopy



IRS P6 LISS IV image on 1: 12,500 scale **Tropical Seasonal Swamp Forest, KAT**

The Tropical Seasonal Swamp Forest occurs as narrow strips along streams and appears in the tone of bright red on FCC

(Table 3.5). These forests were found in all the forest ranges with Sal dominant forests (Nishangada, Dharamapur, and Murtiha) and were mostly found along south-western boundry where they shared their edges with Sal Mixed Forest. A big patch of Open Sal was also found near eastern boundry in Murtiha range (Fig. 3.2 and Fig. 3.5). The over-wood in these forests was composed of scattered Sal trees with low density of 41.1 individuals/ha. The maximum density of 73.9 individuals/ha was found to be of *Mallotus philippensis*. Other associated species were *Tectona grandis*, *Terminalia alata*, and *Syzygium cumini*. Middle canopy comprised *Mallotus philippensis*, *Mitragyna parvifolia*, *Aegle marmelos*, and *Diospyros exsculpta*. Undergrowth was dense. In lower part of the sanctuary, mostly in Murtiha range, *Terminalia alata* was comparatively scarce in top storey. In few patches, middle canopy was found to be dominated by young Teak trees. The overall tree density of the forests was low and hence the canopy density was also low ranging from 20% to 40%.

Mixed Deciduous Forest

These forests occurred on sandy alluvium mostly near river and streams. The presence of miscellaneous species has made this class highly diverse. The common associates were: *Mallotus philippensis*, *Bombax ceiba*, *Syzygium cumini*, *Acacia catechu*, *Haldinia cordifolia*, *Ehretia laevis*, *Trewia nudiflora*, *Lagerstroemia parviflora*, *Aegle marmelos*, and *Diospyros exsculpta*. The canopy density was high and varied between 60% and 80%. These forests covered 11.4% of KAT area (Table 3.5).

Tropical Semi - Evergreen Forest

This forest type typically occurred in wet soils consisting of fine clay and rich humus which is usually found along perennial streams. Katerniaghat forest range offered such environment and thus the maximum area by this forest type was found in Katerniaghat range. It was also found in Sajoli beat of Nishangada forest range and all along Orya *nallah*. The forest type was characterised by presence of cane (*Calamus tenuis*), fern (*Lygodium* *flexuosum*) and several climbers. Prominent tree species found were: *Trewia nudiflora*, *Mallotus philippensis*, *Syzygium cumini*, *Acacia catechu*, *Bombax ceiba*, *Ficus racemosa*, and *Ficus hispida*. This forest type covered 12.4% area of the sanctuary (Table 3.5).

Tropical Seasonal Swamp Forest

This forest type was found in swampy depressions along all streams in water logged areas of the sanctuary (Plate 3.1). Soil aeration was usually poor in these areas and the soil was rich in humus. *Syzygium cumini* formed the main constituent of these forests with maximum density of 96.4 individuals/ha. *Trewia nudiflora*, *Ficus racemosa*, *Mallotus philippensis*, and *Acacia catechu* were other prominent co-associates. The forest type covered 1.6% of KAT area (Table 3.5).

***Terminalia alata* Forest**

These forests were characterised by the presence of pure stand of *Terminalia alata*, which is otherwise found as an associate species in Sal forest. This class was found to be confined to central and north-eastern part of the KAT, particularly in Nishangada and Dharmapur forest ranges (Fig. 3.2 and Fig. 3.5). It occurred within Moderately Dense Sal Forest extending over large areas on clayey alluvial patches. The canopy density varied between 60% and 80% and class covered 13.3 sq km of sanctuary area (Table 3.5).

Khair and Sissoo Forest

This type of forest was found on new sand deposits along streams (Fig. 3.5). It was found in Semri Ghatia forest beat and near Ghumna bhaghar (canal). Khair and Shisham trees dominated this forest type with *Ficus racemosa*, *Trewia nudiflora*, *Bridelia squamosa*, and *Mallotus philippensis* also present in good proportion. The canopy was open and less than 20%. This forest type covered just 0.7% of sanctuary area (Table 3.5).

Table 3.5 - Land Use/Land Cover Classification for Three Constituent Areas of Dudhwa Landscape with Areal Estimates

Constituent Area	DNP		KWS		KAT	
Land Use Classes	**Area (sq km)**	**% Area**	**Area (sq km)**	**% Area**	**Area (sq km)**	**% Area**
Forests						
A. Sal forests						
Dense Sal	77.9	11.4	-	-	12.4	3.1
Moderately Dense Sal	160.2	23.5	48.8	24.0	20.1	5.0
Sal Mixed	25.1	3.7	2.5	1.2	7.9	1.9
Open Sal	120.5	17.7	58.4	28.7	31.7	7.9
Chandar Sal	-	-	9.1	4.4	-	-
Sub total of Sal forests	**383.9**	**56.4**	**118.9**	**58.4**	**72.1**	**18.0**
B. Other forests						
Mixed deciduous	57.0	8.3	14.8	7.3	45.6	11.4
Tropical Semi-Evergreen	14.4	2.1	-	-	49.9	12.4
Tropical Seasonal Swamp	26.8	3.9	1.0	0.4	6.4	1.6
Terminalia alata	-	-	-	-	13.3	3.3
Khair and Sissoo	-	-	-	-	3.0	0.7
Aegle	-	-	-	-	3.0	0.7
Scrub	1.0	0.1	-	-	5.0	1.2
Sub total of other forests	**99.3**	**14.6**	**15.8**	**7.7**	**126.4**	**31.6**
C. Plantations						
Teak Plantation	34.2	5.0	11.4	5.6	38.0	9.5
Other plantations	0.9	0.1	0.1	0.05	4.0	1.0
Sub total of Plantations	**35.1**	**5.1**	**11.5**	**5.6**	**42.0**	**10.5**
Grasslands						
Upland Grassland	41.8	6.1	13.5	6.6	14.4	3.6
Lowland Grassland	95.0	13.9	33.2	16.3	33.0	8.2
Sub total of Grasslands	**136.8**	**20.1**	**46.7**	**22.9**	**47.4**	**11.8**
Wetlands						
River	8.3	1.2	4.3	2.1	46.4	11.6
Swamp/ Water body	7.9	1.1	1.6	0.8	5.0	1.2
Sand Bar	7.9	1.1	2.4	1.2	6.0	1.5
Sub total of Wetlands	**24.1**	**3.5**	**8.4**	**4.1**	**57.4**	**14.3**
Other Land uses						
Fallow Land	0.5	0.08	-	-	40.1	10.0
Habitation	-	-	2.0	0.9	14.4	3.6
Sub total of Other Land Uses	**0.5**	**0.08**	**2.0**	**0.9**	**54.5**	**13.6**
Grand Total	**680.0**		**203.4**		**400.0**	

Aegle Forest

This class occurred on dry clayey soil in extending areas of Open Sal Forest (Plate 3.2). It was confined to the higher areas surrounding river beds, where the thin upper layer of loamy soil had been eroded away from the edges of the 'dammar' and stiff dry clayey sub-soil containing calcareous matter or manganese nodules are exposed (Jha, 2000). It was found in Dharampur and Murtiha forest ranges (Fig. 3.2 and Fig. 3.5). These forests represented pure stand of *Aegle marmelos* but at many places was mixed with *Diospyros exsculpta*, *Acacia catechu*, *Tectona grandis*, *Cordia dichotoma*, and *Azidrachta indica*. The canopy was open about less than 20% and tree growth was stunted. These forests covered only 0.7% area of KAT (Table 3.5).

Scrub

This vegetation type occurred on the river islands of Girwa and Kauriyala Rivers. These islands comprised of fresh alluvium and were devoid of trees. *Tamarix dioica* shrub dominated these islands and *Saccharum spontaneum* was the dominant grass species. Scrub covered 1.2% area of the sanctuary (Table 3.5).

Teak Plantation

Extensive plantations of Teak, an exotic species to this tract were recorded in KAT. It occurred in good proportion in all the forest ranges (Fig. 3.5). In many areas, it was found to be so successful that clear stratification with *Mallotus philippensis*, *Mitragyna parvifolia*, *Aegle marmelos*, etc. in middle storey was clearly visible. Top storey was shared by *Lagerstroemia parviflora*, *Shorea robusta*, *Terminalia alata*, and *Ehretia laevis*. The canopy density was high and ranged between 60% and 80%. These forests covered 9.5% of KAT area (Table 3.5).

Other Plantations

This vegetation type comprised of plantation species, mainly of *Eucalyptus citriodora*, *Acacia catechu*, *Dalbergia sissoo*, *Terminalia arjuna*, *Trewia nudiflora* and *Dendrocalamus strictus*. *Eucalyptus* plantations were found along railway line, roads and in ‘grassy blanks’ (Plate 3.2). Khair and Shisham plantations were maximum in Sajuli forest beat whereas Bamboo plantations were found near Purena *taal* in Murtiha range and Dharmapur forest range. These plantations covered 1.0% of area (Table 3.5).

Upland Grassland

These types of grasslands were found as grassy blanks on well drained soils within the Sal forest (Plate 3.4). The dominant grasses included *Cyrtococcum patens*, *Desmostachya bipinnata*, *Imperata cylindrica*, and *Cymbopogon jwarancusa*. Some Upland Grasslands had scattered tree growth of species such as *Bombax ceiba*, *Dalberbia sissoo*, *Acacia catechu*, *Lagerstroemia parviflora*, and *Tectona grandis*. The Upland Grassland covered 3.6% of sanctuary area (Table 3.5).

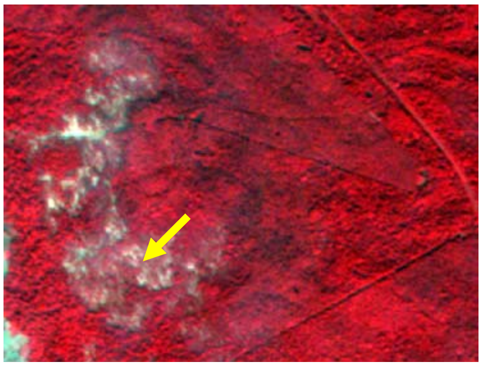
Lowland Grassland

This class of grasslands was found in low lying areas or water logged depressions (Plate 3.4). Depressions are remaining old river channel course. The prominent grass species were *Phragmites karka*, *Saccharum narenga*, *Saccharum spontaneum*, and *Schlerostachya fusca*. These grasslands had interspersed swamps and covered 8.2% area of the sanctuary (Table 3.5). The maximum percentage of Lowland Grassland was found in Katerniaghat forest range.

Swamp and Water Bodies

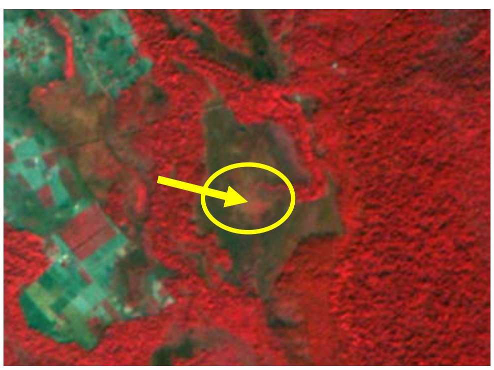
This category included interspersed swamps and small natural water bodies within KAT (Plate 3.3). They both covered 1.2% of sanctuary area (Table 3.5).

Plate 3.2 - Images of IRS P-6 LISS IV Showing Characteristic Image Recognition Patterns of *Aegle* Forest and *Eucalyptus* Plantations in Dudhwa Landscape and their Corresponding Picture on Ground



IRS P6 LISS IV image on 1: 12,500 scale   ***Aegle* Forests, KAT**

***Aegle* Forests are unique to KAT. The canopy is open and these forests thus appears as white patches on FCC**



IRS P6 LISS IV image on 1: 12,500 scale   ***Eucalyptus* plantation, KAT**

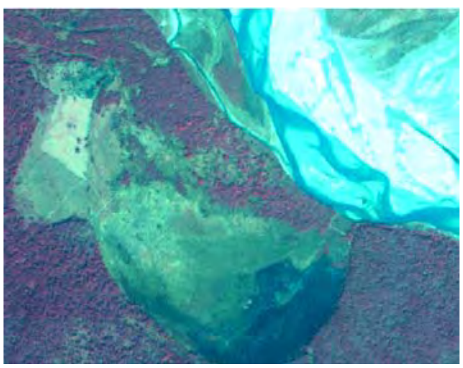
***Eucalyptus* plantations are one of many plantations found in Dudhwa landscape. These usually are found along railway line, road side and in grassy blanks and occur in the tone of pink**

Plate 3.3 – Images of IRS P-6 LISS IV Showing Characteristic Image Recognition Patterns of Water Logged Area and *taal* in Dudhwa Landscape and their Corresponding Picture on Ground

IRS P6 LISS IV image on 1: 12,500 scale

Suheli River, DNP

The arrow represents the water logged area near Dudhwa campus in DNP and the photo on the right presents the silt deposit on the boundary of the Suheli River after dredging

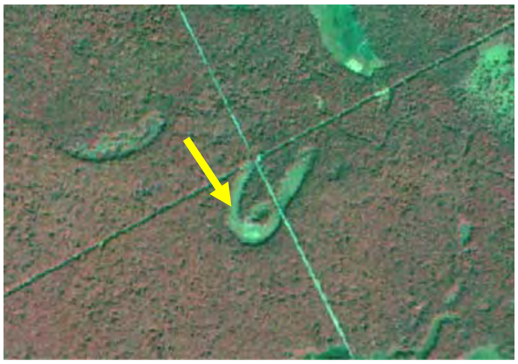


IRS P6 LISS IV image on 1: 12,500 scale

Jhadi *taal*, KWS

The image represents the famous Jhadi *taal* of KWS bordered by Sharda River. The photo on the right presents picture of it representing the characteristics woodland-grassland-wetland complex of Dudhwa landscape

Plate 3.4 – Images of IRS P-6 LISS IV Showing Characteristic Image Recognition Patterns of Grasslands in Dudhwa Landscape and their Corresponding Picture on Ground



IRS P6 LISS IV image on 1: 12,500 scale

Upland Grassland, KAT

Upland Grasslands are found as grassy blanks on well drained soils inside the Sal forest. These grasslands emerge in the tone of greenish yellow on satellite data

IRS P6 LISS IV image on 1: 12,500 scale

Lowland Grassland, KAT

Lowland grasslands are found in low lying areas or water logged depressions along rivers and streams. These grasslands have interspersed swamps and appear in the light to dark bluish green tone

Rivers and Streams

This category included major rivers and streams of the sanctuary. It comprised Girwa and Kauriyala Rivers which traverse through Katerniaghat forest range and stream like Orya *nallah*. The canal which passes through a small stretch of KAT was also included in this class. River and streams covered a substantial area of the sanctuary, being 11.6% (Table 3.5).

Sand Bar

This non-forest class included islands and sand deposition along and within the rivers and covered 1.5% of the sanctuary area (Table 3.5).

Fallow Land

The fallow land and farm land within KAT were classified into fallow land category which covered 10.0% of the area (Table 3.5).

Agriculture

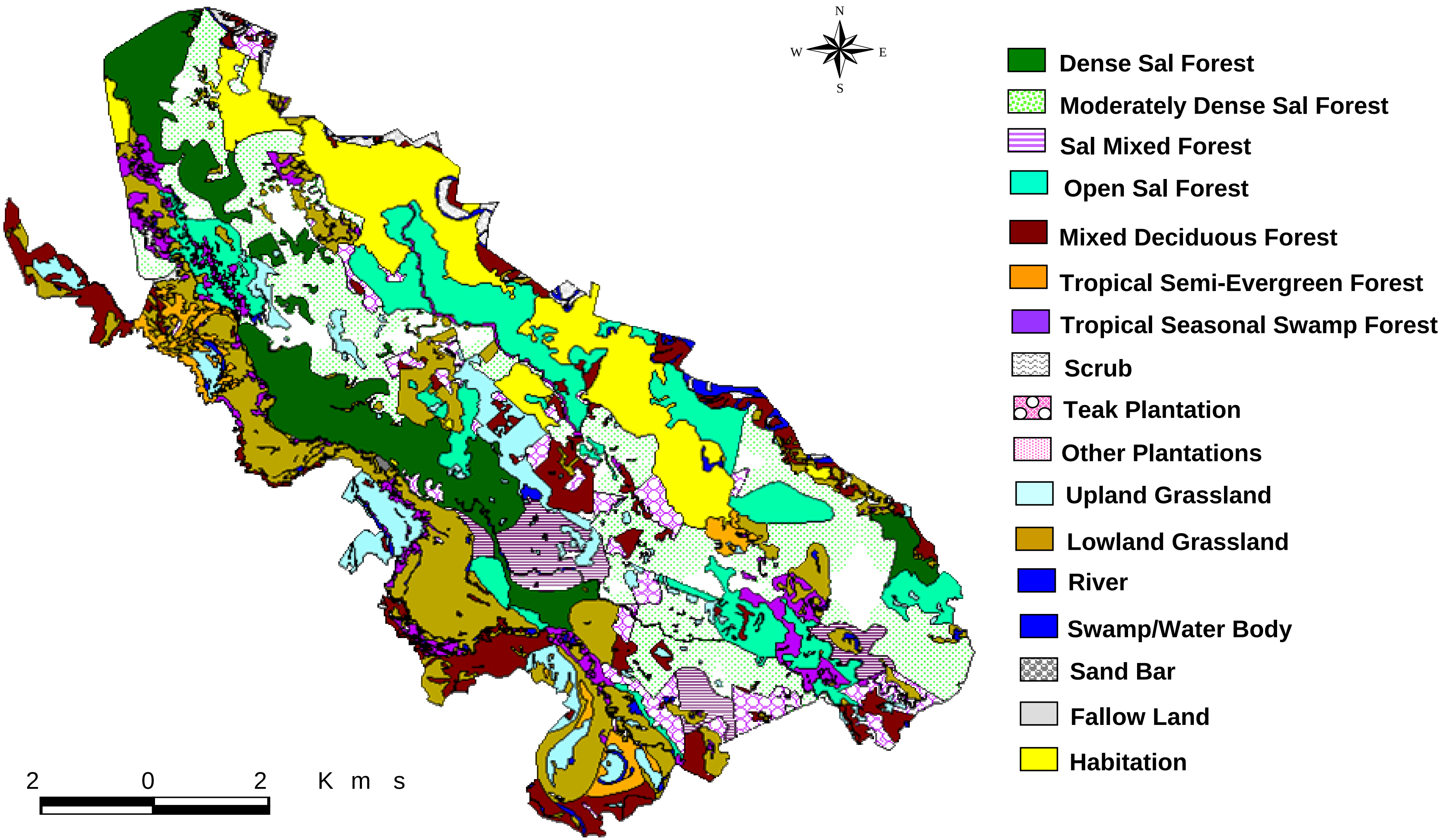
This non-forest class included the settlements and agricultural land of the villages present within the boundry of the sanctuary and covered 3.6% of KAT area (Table 3.5). The common crops grown in the area included sugarcane, paddy, wheat, and turmeric.

(b) Land use/land cover in DNP

The land use map for DNP is presented in Fig. 3.6, while land use classes, area, and percent extent are given in Table 3.5**.** The description of the distribution and areal extent of land use classes in DNP is presented in the following sections.

The forestland of DNP (680.0 sq km) was represented by forests-71.0%, plantations-5.1%, grasslands-20.1%, wetlands-3.5%, and others-0.08%

Fig. 3.6 - Land Use/Land Cover of DNP Developed from IRS P-6 LISS IV at the Scale of 1:25,000



(Table 3.5). Sal dominated forests predominately occupied DNP as they covered 56.4% area or 383.9 sq km of DNP in contrast to just 18.0% Sal forests in KAT (Table 3.5). The percentage proportion of Dense Sal in DNP was obviously much high i.e. 11.4%. Among four types of Sal forests in DNP, Moderately Dense Sal Forest occupied the maximum area (23.5%). Other Forests (Mixed Deciduous Forests, Tropical Semi-Evergreen Forests, and Tropical Seasonal Swamp Forest) covered 99.3 sq km or 14.6% area of DNP. The Mixed Deciduous Forests were the main contributor in this case. Fig. 3.6 illustrates distribution of different Sal forest types in DNP. The Dense Sal and Open Sal Forests were found mostly along the south-western and north-eastern boundaries of National Park, respectively while the Moderately Dense Sal Forests were found as a sandwich between two extreme Sal types. Amongst the Other Forest types i.e. Tropical Seasonal Swamp Forest and Tropical Semi-Evergreen Forest were found mostly along Suheli River and covered small area of about 4% and 2%, respectively while Mixed Deciduous Forests occupied areas along both south-western and north-eastern boundry of the park. The Teak Plantation represented nearly 5% area of the park whereas the Other Plantations together occupied just 0.1% area. Upland and Lowland Grasslands occurred in the ratio of 1:2.26 with Lowland Grasslands occupied a significant area of about 14% and were found all along Suheli River. The river system in the park was represented by narrow rivers like Suheli and Mohana and numerous streams that flow within the park and in total the flowing water occupied little over 1% area of the park (Table 3.5). Analogously, the swamps also represented 1.17% area of the park. The varying sized sand bars along Suheli and Mohana Rivers covered 1.16% area. A distinct small sized water logged area covering just 0.08% area was also delineated in the park (Plate 3.3).

(c) Land use/land cover in KWS

The land use/land cover analysis in the context of KWS revealed that the sanctuary was represented by Sal forests-58.4%, other forests-7.7%, plantations-5.5%, grasslands-22.9%, wetlands-4.1%, and a small extent of (0.9%) of habitation and agriculture under two villages located within the sanctuary (Table 3.5 and Fig. 3.7). KWS was found to be unique in terms of presence of *Chandar* Sal. About 5% area of the sanctuary was confined by *Chandar* Sal Forest (Table 3.5). Unfortunately, Dense Sal Forest class was missing in KWS and Open Sal Forests represented the maximum area of the sanctuary (58.4 sq km or 28.7%) and also all Sal forest types. In Other Forests category, only Mixed Deciduous Forest and Tropical Seasonal Swamp Forest were registered in sanctuary, all other classes were missing. Both were recorded from areas along Sharda and Ull Rivers. Among plantations, Teak occupied nearly 6% area whereas Other Plantations contributed negligibly in area occupancy. Similarly as Sal forests, two types of grassland also occupied significant area around 46.7 sq km or 23% of the sanctuary. The Upland and Lowland grasslands occurred in the ratio of 1:2.45. The Lowland grasslands were located along Sharda and Ull Rivers. The river system in the sanctuary was mainly contributed by a stretch of Sharda River and Ull River flowing from middle of the sanctuary and covered an area of 2.13% whereas swamps occupied area less than 1% (Table 3.5, Fig. 3.7). The sand bar and agriculture also covered nearly 1% each.

(d) Land use/land cover in Dudhwa landscape

The assessment of land use/land cover patterns of Dudhwa landscape revealed that the landscape was covered by Sal forests-44.8%, Other Forests-18.8%, plantations-6.9%, grasslands-18.0%, wetlands-7.0%, and other land uses-4.4% (Table 3.6 and Fig. 3.8). The other land use mainly included land under the control of two government farms, habitation along with their agriculture in KWS and KAT, and a small patch of forest converted water logged area in DNP. Area under habitations along with extensive agriculture in the north DNP is excluded in above statistics. The class of Moderately Dense Sal Forest was the prominent class in the landscape in terms of actual area of coverage (229.2 sq km). This was followed by Open Sal Forests occupying 16.4% of the landscape. The Lowland Grasslands represented the third largest land use/land cover class as it occupied 161.2 sq km area or 12.5% of the landscape. In the category of Other Forests, Mixed Deciduous Forest was the prominent class and it covered 9.1% of the

Fig. 3.7 - Land Use/Land Cover of KWS Developed from IRS P-6 LISS IV at the Scale of 1:25,000

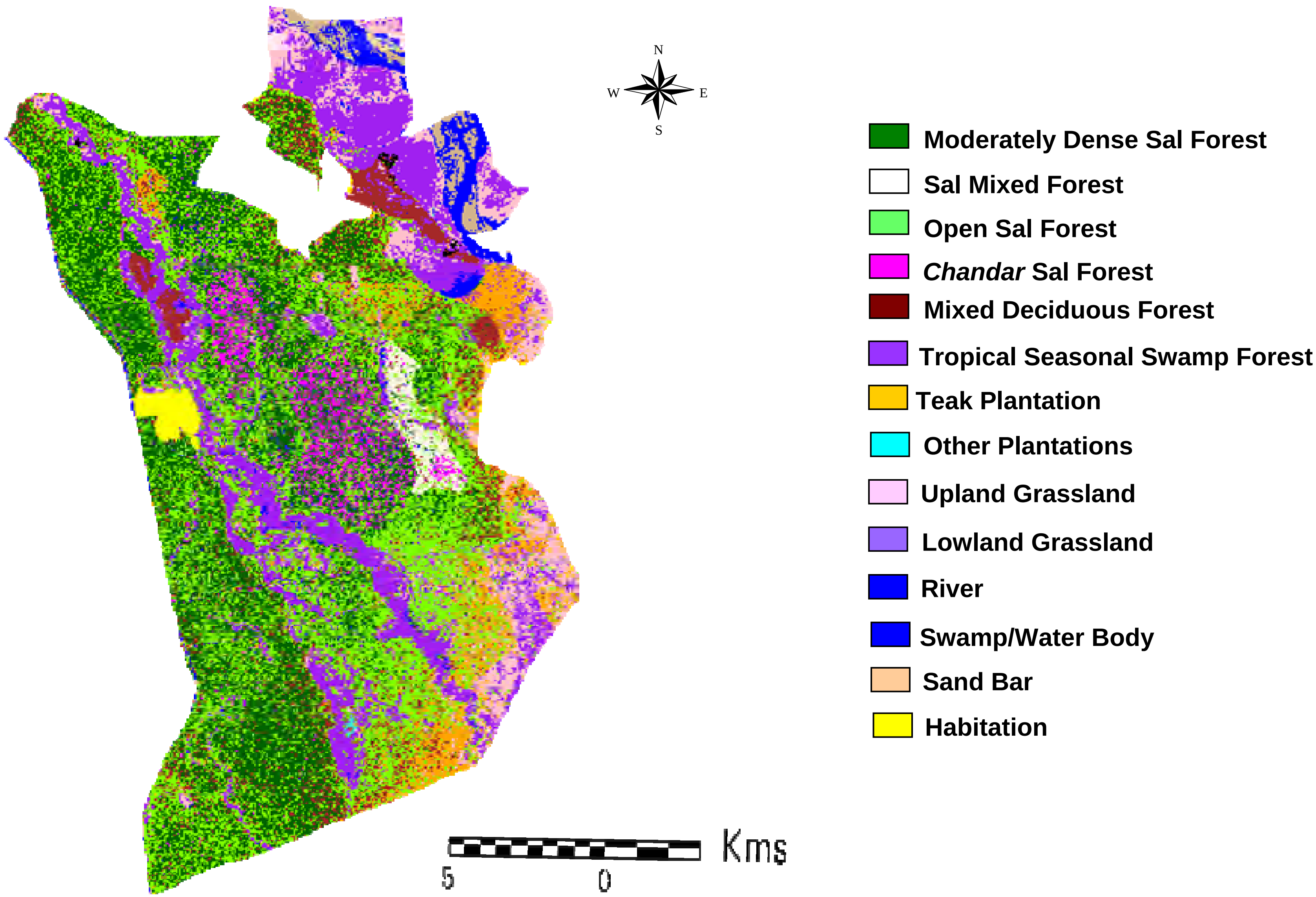
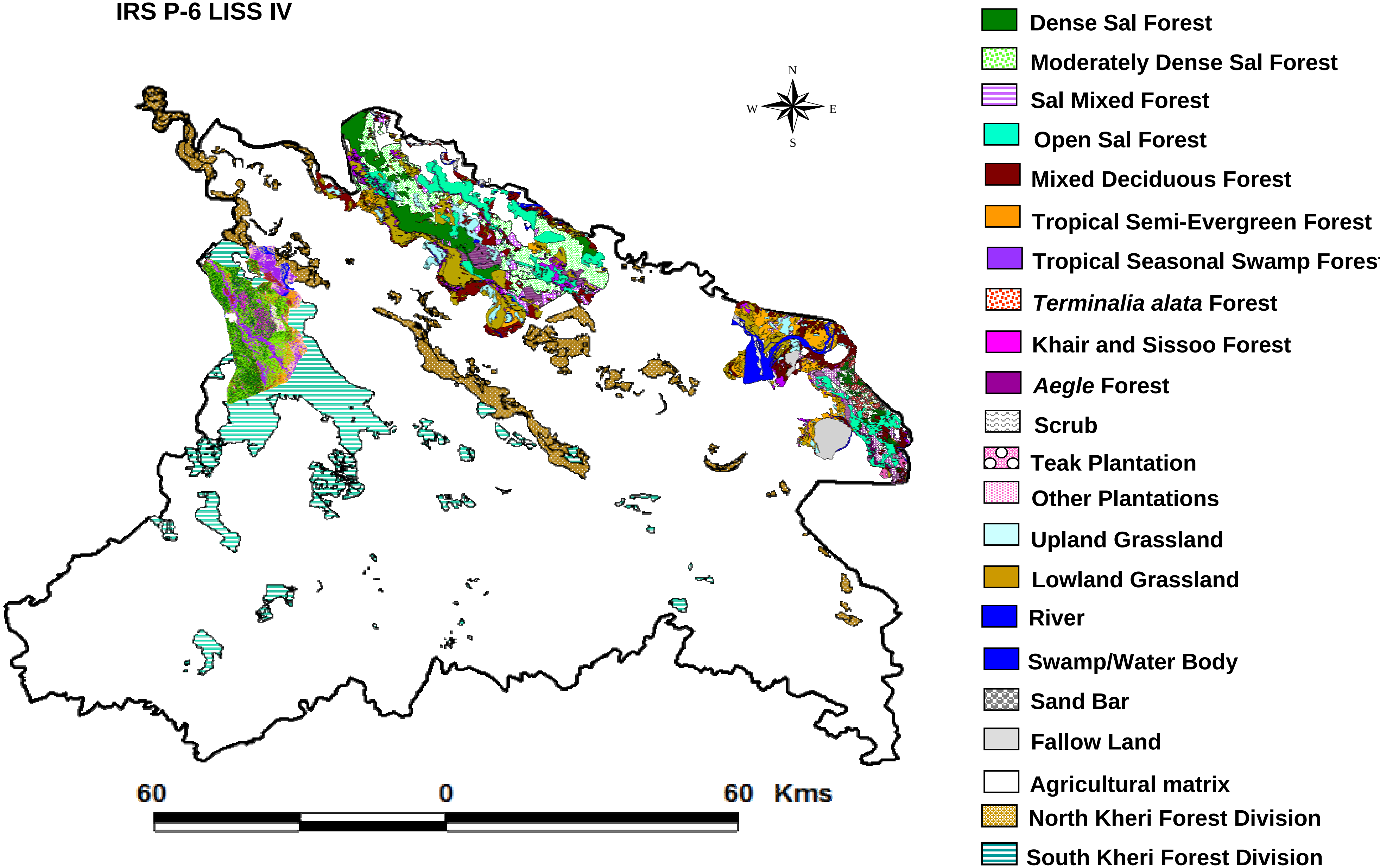


Fig. 3.8 - Land Use/Land Cover of Dudhwa Landscape Developed from IRS P-6 LISS IV



landscape (Table 3.6). The Tropical Semi-Evergreen Forests and Tropical Seasonal Swamp Forests represented 5.0% and 2.6% of the landscape, respectively. *Terminalia alata* Forest, Khair and Sissoo Forest and *Aegle* Forest occurred in low extent only.

Accuracy Assessment: The overall accuracy computed for the land use/land cover map was 91.3% and overall Kappa statistics was 0.9.

(e) Comparison of land use/land cover in constituent areas

Keeping the differences in actual area of three protected areas aside, they were compared keeping in view that they all belong to same *Terai* tract and must had been part of one contiguous forest at one time. The comparison has revealed some interesting facts.

Analysis revealed that amongst three PAs, actual area extent of the Sal forest was found to be maximum in DNP, followed by KWS and KAT, respectively. On the contrary, the % areal extent was maximum for KWS despite it being almost one-fourth the size of national park. Albeit, such high % of its area being covered by Sal forests but mostly it was low Sal density forest i.e. Open Sal. Notably, KWS totally lacked the category of Dense Sal Forest. One more interesting feature was the confinement of another Sal forest type i.e. *Chandar* Sal Forests only in KWS. Analogously, in KAT also, Open Sal Forests registered maximum area followed by Moderately Dense Sal Forest. This indicated that the national park still enjoys its maximum area under Moderately Dense Sal Forest followed by Open Sal Forest. The contradiction pointed towards the benefit of protection that the national park enjoyed for such a longer period than the two sanctuaries.

Regrettably, DNP had also been facing pressure from across the international border and enclave *Tharu* habitations in the buffer area. This was clearly endorsed by distribution pattern of different Sal forest types as revealed by the land use/land cover maps (Fig. 3.6). The presence of Open Sal Forest on

Table 3.6 - Land Use/Land Cover Classification for Dudhwa Landscape with Areal Estimates

Land use/Land Cover Classes	Area (sq km)	% Area
Forests		
A. Sal forests		
Dense Sal Forest	90.3	7.0
Moderately Dense Sal Forest	229.2	17.8
Sal Mixed Forest	35.6	2.7
Open Sal Forest	210.7	16.4
Chandar Sal Forest	9.1	0.7
Sub total of Sal forests	**575.0**	**44.8**
B. Other forests		
Mixed Deciduous Forest	117.5	9.1
Tropical Semi-Evergreen Forest	64.3	5.0
Tropical Seasonal Swamp Forest	34.3	2.6
Terminalia alata Forest	13.3	1.0
Khair and Sissoo Forest	3.0	0.2
Aegle Forest	3.0	0.2
Scrub	6.1	0.4
Sub total of Other Forests	**241.6**	**18.8**
C. Plantations		
Teak Plantation	83.6	6.5
Other plantations	5.0	0.3
Sub total of Plantations	**88.7**	**6.9**
Grasslands		
Upland Grassland	69.7	5.4
Lowland Grassland	161.2	12.5
Sub total of Grasslands	**231.0**	**18.0**
Wetlands		
River	59.0	4.6
Swamp/ Water body	14.5	1.1
Sand Bar	16.3	1.2
Sub total of Wetlands	**90.0**	**7.0**
Other Land uses		
Fallow Land	40.6	3.1
Habitation	16.4	1.2
Sub total of Other Land Uses	**57.0**	4.3
Grand Total	**1283.5**	

the north-eastern boundary along the international border evidently indicated the pressure from Nepal and nearby habitations. Similarly in KAT, Dense Sal Forest and Moderately Dense Sal Forest were confined to middle of the sanctuary in Nishangada forest range again pointed towards the pressure from surrounding areas (Fig. 3.5).

Striking variations were found in Other Forest category in three PAs. In KAT, six different Other Forest types were deciphered and also registered maximum area under this category in the entire Dudhwa landscape. Among the six Other Forest classes, *Terminalia alata* Forest was the most unique category; it was confined to KAT only and existed in almost pure stand, albeit being an associate of Sal. Other classes confined only to KAT included *Aegle* Forest and Khair and Sissoo Forest. The Mixed Deciduous Forest and Tropical Seasonal Swamp Forest were common to all three PAs whereas Tropical Semi-Evergreen Forest were found in DNP and KAT. The areal extent of Mixed Deciduous Forest was maximum in DNP followed by KAT. The KAT registered maximum area of Tropical Semi-Evergreen Forest due to the occurrence of wide spread river system in Katerniaghat forest range (Fig. 3.2).

The land use/land cover analysis revealed that the extent of the plantations especially of Teak is quite large in KAT as compared to DNP and KWS. This indicated that Teak had been widely planted and it has established itself very well in KAT. The % extent of other land use was also found to be large in KAT, due to large part of its area being utilized as the government farm. The problems arising due to two farms have been raised by management several times and it has been also cited in the management plan of KAT (Jha, 2000).

Dudhwa landscape is true representative of enormous river system of *Terai*. The statement was corroborated by results of analysis. Cumulatively, nearly 74 sq km or 5.7% of the landscape was represented by rivers and swamps. The KAT contributed maximum area as about 12% or 46.4 sq km of its area was under flowing water. The two wide rivers Girwa and Kauriyala in Katerniaghat forest range were responsible for such a large extent of area whereas in DNP, narrow rivers like Suheli, Mohana, and numerous streams contributed about 8.3 sq km of area (Fig. 2.3; Fig. 3.5; Fig. 3.6). About 2% area in KWS was also under this category. Interestingly, regardless of such a large extent of area with flowing water in KAT, the area under swamps was highest in DNP followed by KAT and minimum in KWS.

The massive water system in KAT was responsible for making one of its forest range i.e. Katerniaghat very unique. The entire area under this forest range was devoid of most dominating tree of this tract i.e. Sal. The complete range was an intricate mixture of Lowland and Upland Grasslands, Tropical Semi-Evergreen Forest, Tropical Seasonal Swamp Forest, Mixed Deciduous Forest, and Teak Plantation (Fig. 3.2 and Fig. 3.5). The unique assortment thus harbours some of the endangered and obligate species of *Terai*.

The similar inimitable collection can be found all along south-western boundry of DNP in Sathiana and Kakraha areas and along Sharda River in KWS (Fig. 3.6). The famous Jhadi *taal* (KWS); Kakraha *taal* (DNP); Bankey *taal* (DNP); and Chapra *taal* (DNP) and many more are result of the wide spread water system. The grasslands surrounding these wetlands act as an important habitat. Observations on grasslands in Dudhwa landscape revealed a notable result. For whatsoever reason, the ratio of Upland to Lowland Grassland in three studied PAs was almost same, (DNP-1:2.26; KWS-1:2.45; and KAT-1:2.29). The DNP harboured maximum area under grasslands followed by KAT and KWS, respectively. Similarly as in the case of Sal forests, KWS being smallest in size reported maximum % area of two types of grasslands, being 22.97%.

The foregoing section provided an insight on the land use/land cover patterns in the Dudhwa landscape and its constituent areas. The following section presents results on the evaluation of effectiveness of high resolution data and endorses its expectations.

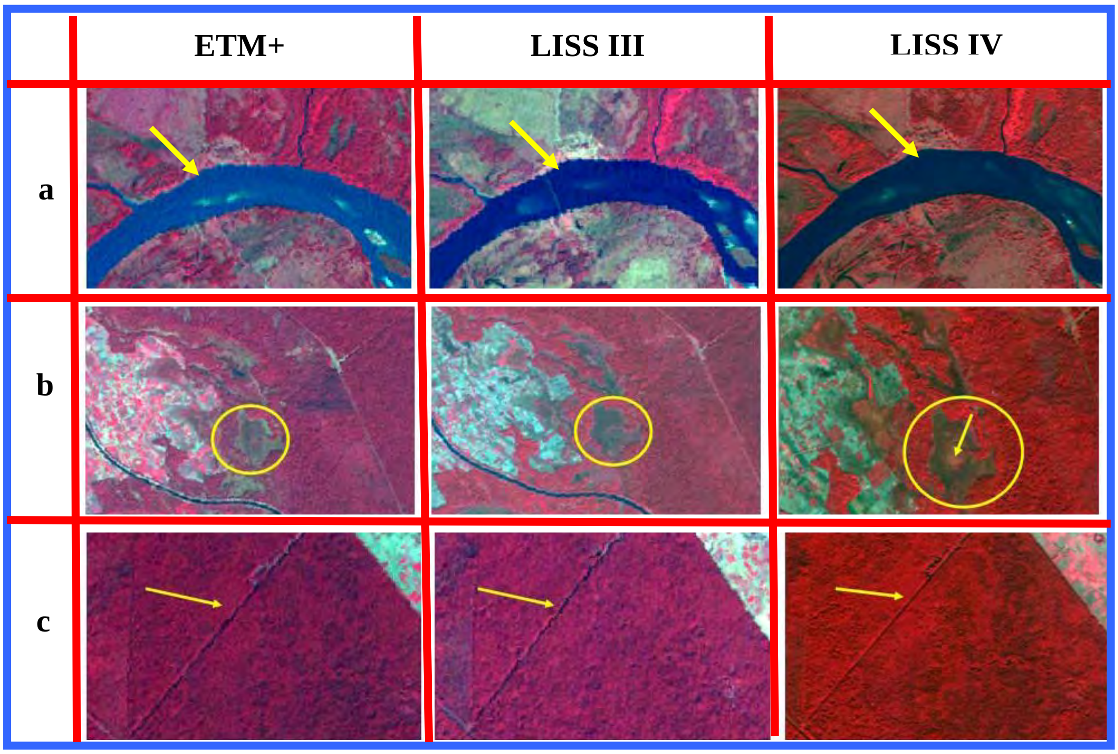
3.4.2 Effectiveness of High Resolution Data (LISS IV) for Land Use Mapping

The present study assessed efficacy of high resolution data for improved planning and management of PAs. Finding on qualitative and quantitative assessment of LISS IV are presented below:

(a) Qualitative assessment of LISS IV

Visual analysis of images of the sample sites in KAT extracted from LANDSAT ETM+, IRS 1D LISS III and IRS P-6 LISS IV revealed more contrast among features in LISS IV as compared to other datasets owing to its high spatial resolution. The boundaries were more precise and easy to delineate in LISS IV. Few examples of more accurate boundary delineation and possible identification of small important patches of otherwise a suppressed distinct vegetation type within other surrounding vegetation type are presented in Fig. 3.9. In case of LISS IV, presence of contrast and discernible bank line were evident (Fig. 3.9 a). High resolution imagery of LISS IV allowed better demarcation of grassland boundaries and delineation of a plantation patch within, which was otherwise invisible in ETM+ and LISS III (Fig. 3.9 b). Similarly, contrast tone and texture of Dense Sal Forest was conspicuous within other forest types in case of LISS IV (Fig. 3.9 c). Delineation of boundaries of Dense Sal Forest in medium resolution datasets (ETM+ and LISS III) was confusing.

All linear features such as metalled road, forest road, railway line, etc were very clear and easy to extract in LISS IV, except in some places where the contrast was relatively low. In case of both the medium resolution datasets, it was difficult even to identify the adjacent railway and metalled road. Unfortunately, point features such as water wells and single trees were impossible to be detected in any of the datasets.



a: Arrow indicates contrast and discernible bank line in LISS IV
b: Circle indicates distinctive grassland boundry and added information on the patch of eucalyptus plantation within grassland as indicated by arrow
c: Arrow indicated contrast tone and texture of Dense Sal Forest

Fig. 3.9 - Images of Land Use Features for Visual Comparison between Landsat ETM+, IRS 1 D LISS III, and IRS P-6 LISS IV

(b) Quantitative assessment of LISS IV

The results demonstrated that the extent of three linear features i.e. metalled road, forest road, and railway line mapped from LISS IV was much more than other datasets. Statistics of the length of the features mapped is given in Table 3.7. The comparison indicated that the extent of the railway line mapped from three datasets was almost identical. Likewise, the length of metalled road extracted from LISS IV and LISS III was also almost equal. On the contrary, a significant difference in the extent of the main road mapped from LISS IV and ETM+ was recorded (Table 3.7). Forest roads mapped using three datasets allowed remarkable distinction in length. Fig. 3.10 also illustrates the distinction in extent of extraction in forest roads. The metalled road was not at all clear in ETM+ data and got merged with adjacent railway line. In case of forest roads, difference in the extent of mapping between three datasets was apparent. The length of the forest road extracted in LISS IV was much higher, being 112% in comparison to ETM+. The enhancement of such extraction was only to the extent of 16.5% from ETM+ (30 m) to LISS III (23.5 m) and enhancement from LISS III to LISS IV was to the extent of 82% (Table 3.7; Fig. 3.10).

Table 3.7 - Length of Linear Features Extracted from Landsat ETM+, IRS 1 D LISS III, and IRS P-6 LISS IV (Values in km)

Category	LISS IV	LISS III	ETM+
Railway line	12.92	12.82	12.84
Main Road	2.52	2.51	0.00
Forest Road	49.70	27.29	23.42

The comparison of land cover maps derived from LISS III and LISS IV revealed that in both the datasets, seven vegetation classes were delineated (Fig. 3.11). To compare the concordance area (mutual agreed area of a vegetation type deciphered from two datasets – LISS III and LISS IV), a confusion matrix was generated (Table 3.8).

Accordingly, the major diagonal of the matrix (running from upper left to lower right) indicates concordance. For example, out of 483.9 ha area of Dense Sal Forest delineated by LISS IV, the concordance area with LISS III was 148.8 ha i.e. 30.7% coincidence (Table 3.8). The remaining area (335.1 ha) of Dense Sal Forest was misclassified by LISS III into three different classes (Moderately Dense Sal Forest, *Terminalia alata* Forest, and Teak Plantation).

The maximum mismatch was with Moderately Dense Sal Forest indicating that LISS IV was able to segregate two most close classes accurately. The values of % coincidence for other six forest classes ranged from 30.7% to 100% in case of Dense Sal Forest and Upland Grassland, respectively.

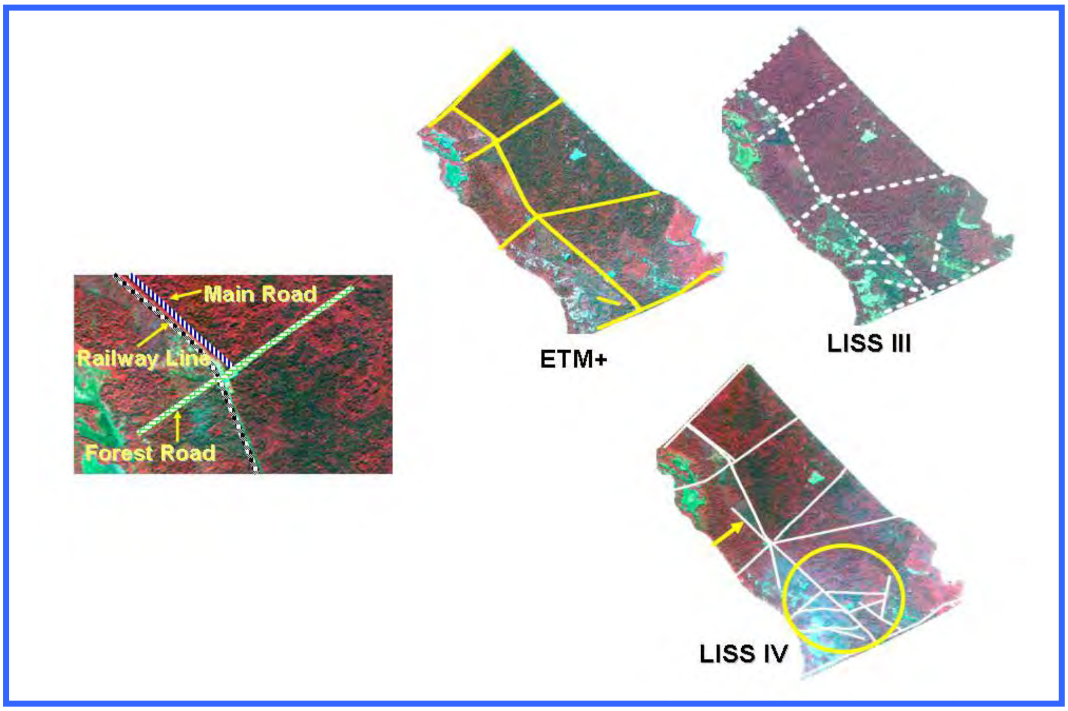


Fig. 3.10 - Linear Features (Metalled Road, Forest Road, and Railway Line) Extracted from Landsat ETM+, IRS 1D LISS III, and IRS P-6 LISS IV

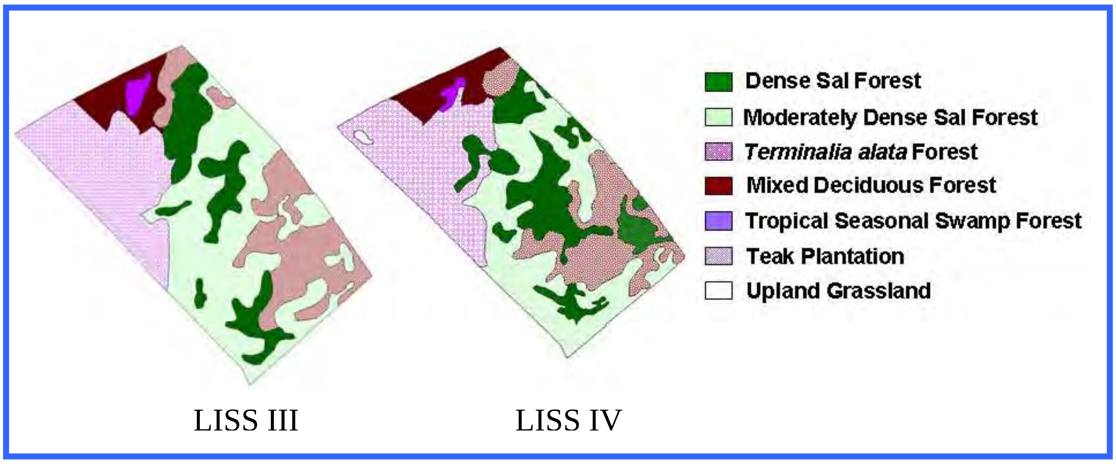


Fig. 3.11 - Land Cover Maps Derived from IRS 1D LISS III and IRS P-6 LISS IV

The values of % coincidence were found to be high for Mixed Deciduous Forest and Teak Plantation being 89.7% and 89.2%, respectively. Higher values indicated that the both datasets classified them near equally due to their distinct tone and texture. Only Upland grassland obtained a value of 100% coincidence. The overall % coincidence was found to be 66.4%.

Table 3.8 - Concordance Area (ha) of Land Use Classes Based on IRS 1D LISS III and IRS P-6 LISS IV

Land Cover Classes from LISS III	Land Cover Classes from LISS IV						
	Dense Sal	Moderately Dense Sal	*Terminalia alata*	Mixed Deciduous	Tropical Seasonal Swamp	Teak Plantation	Upland Grassland
Dense Sal	148.8	68.8	40.9	0.3		19.5	
Moderately Dense Sal	229.1	483.4	146.3			1.8	
Terminalia alata	73.3	86.6	254.8			13.6	
Mixed Deciduous				98.1	2.5	18.8	
Tropical Seasonal Swamp				6.7	13.3	6.3	
Teak Plantation	32.6	10.0		4.0	0.8	500.9	
Upland Grassland							6.6
Total	**483.9**	**648.9**	**442.1**	**109.3**	**16.7**	**561.2**	**6.6**
% Coincidence	**30.7**	**74.5**	**57.6**	**89.7**	**79.5**	**89.2**	**100.0**

3.5 Discussion

The following section specifically discusses the impact of land use on current biodiversity in Dudhwa landscape and effectiveness of high resolution data.

3.5.1 Human Land Use and Biodiversity

Like other species, humans generally do not settle randomly on the landscape. Rather, human density and land use are often located to maximise access to critical resources (Hansen and Rotella, 1999). Patterns of human settlement and associated activities *viz.* land use intensification, land cover conversion and land degradation have profoundly influenced forest structure and heterogeneity worldwide for millennia (Burgess and Sharpe, 1981; Spies and Turner, 1999). Forest landscape patterns result from the interplay of abiotic constraints, biotic interactions, and disturbances. The forces that cause forest dynamics also result in spatial patterning. Forest dynamics and spatial heterogeneity are closely linked. Spatial pattern can exert a strong influence on population dynamics, ecological processes, and ecosystem integrity. Past decades eye witnessed abrupt and swift human settlements in Dudhwa landscape, coupled with speedy land-cover conversion, land-use intensification, and ensuing land degradation. Under these conditions, understanding of land-use and consequential spatial patterns on a fine scale using modern tools of high resolution remote sensing and GIS were considered of utmost importance.

(a) Fine scale mapping and spatial patterns

Protected areas, managed forest, other lands including private lands (habitation and agriculture) constitute Dudhwa landscape. The first effort of land use/cover mapping for one of the constituent areas or 'landscape management units (LMU) i.e. DNP was initiated way back in 1985 using Landsat MSS (Singh, 1985). This yielded the first broad based land use classification for DNP. This was followed by a study in a much larger area 'Terai Conservation Area' incorporating DNP, KWS, NKFD, SKFD, and vast intervening lands (Kumar *et al*., 2002). Study used a medium resolution data IRS IC LISS II with a resolution of 36.5m and provided the first spatial database for TCA on 1:50,000 scale. Land use classification developed by Kumar *et al.* (2002) included 17 land use categories. The study could not include KAT - one of LMUs and generated output maps on a small scale. Present effort was to overcome these two deficiencies and produce a comprehensive, updated land use maps for Dudhwa landscape including KAT on a fine scale of 1:25,000 using a high spatial resolution data (IRS P-6 LISS IV, 5.8m). Use of high resolution data in the present investigation allowed delineation of four additional land use classes besides 17 classes already reported by previous study. New additions were: *Terminalia alata* Forest, *Aegle* Forest, Fallow Land, and a fourth category making distinction between Teak Plantations and Other Plantations. The maps generated serve as vital baseline information and indicates that the present landscape conditions represent a complex of forest - grassland - wetland and these three inter-related entities are in an approximate ratio of 70:23:07 respectively. Another, significant current baseline information is in the form of diversity and extent of Upland and Lowland grasslands in three LMUs. Accordingly, Upland and Lowland grasslands need to be ideally maintained in 1:2.3 ratio. Rivers and swamps are obligatory for the maintenance of integrity of this unique forest-grassland-wetland complex and also of two types of grasslands. The disturbance regime i.e. flooding or fluvial action is central to the overall dynamics of the landscape. Notably, KAT registered a significantly high proportion of area under rivers and swamps as compared to DNP and KWS. KAT and to some extent KWS enjoy the benefit of fluvial action by wide and larger river system while in case of DNP only two relatively small rivers - Suheli and Mohana are responsible to perform similar fluvial function. Human induced alterations upstream and within the landscape may further modify necessary fluvial functions of these two rivers. Yet another revelation made by the present study with regard to the occurrence and distribution of Open Sal forests on the peripheral areas, in both DNP and KAT alarms the influence of biotic pressure from across the international border as well as from local communities. If unchecked, this pressure may affect Moderately Dense Sal Forest and Dense Sal Forest those are otherwise presently appeared to be safe due to their distant location from periphery towards forest interiors or central part of the LMU. In three investigated LMUs, plantations of exotic species (Teak, *Eucalyptus*) have occupied a significant area ranging from 5.1% in DNP to 10.5% in KAT. This has remarkably influenced native biodiversity. Adaptive management approach is required for removal of such exotics. Further, in case of KAT, the two government Farms covering nearly 10% area has not only affected native biodiversity but also dispersal and movement corridors for wild animals. Necessary correction of this undesirable situation by the management is required on a priority. Noticeably, each constituent area/LMU investigated also represents featured characteristics in terms of occurrence, distribution, and extent of land use/land cover classes delineated by the present study. Details on such characteristics features/differences have already been discussed in para 3.4.1 (e) and this calls for equal importance and management of each of the LMU as they contained a few characteristics classes that too in a very small extent (e.g. *Aegle* Forest in KAT, *Chandar* Sal forest in KWS).

(b) Effectiveness of high resolution data

Several authors have highlighted the improved ability of high resolution data for mapping in different sectors or development of spatial information (Gupta and Jain, 2005, Clarke *et al*., 2004, Faour and Kheir, 2002). High resolution data i.e. IRS P-6 LISS IV used and validated in the present investigation has also been deployed by various users for extracting spatial information relevant to different disciplines and they have also commented favourably on its improved ability. Kumar and Martha (2004) assessed the capability of LISS IV for geological studies in Uttarakashi region of Uttaranchal by comparing it with LISS III-PAN merged data. The study revealed that major fault zone, minor joint trends, old landslide zone, different level of river terrace were better discernible in LISS IV as compared to merged data. Features in the shadow region like break in slope, structural lineament were clearer in LISS IV. Ramesh *et al*. (2004) studied urban land use/cover of parts of Delhi region using LISS IV and concluded that detailed land use with field boundaries were delineated upto level III and road network were extracted upto level II using LISS IV. They also remarked that LISS IV data is comparable to IKONOS (4m; Mx) data for field level mapping. In another comparative study, Shanker (2004) evaluated the efficacy of LISS IV and LISS III in estimating water spread area. Study reported that reservoir water spread area obtained from LISS IV and LISS III are comparable. However, error associated with delineation of border (mixed) pixels and contour generation was significantly lower in case of LISS IV. Hence, the study concluded that LISS IV is useful for improved accuracy in reservoir water spread estimation, especially for small to medium sized reservoirs and thus can be helpful in sedimentation studies.

LISS IV was also found valuable in estimating area and number of small glaciers and ice field in an investigation on retreat of glaciers in Chenab, Parbati and Baspa basins in Himachal Pradesh by Kulkarni *et al*. (2007). Bahugana (2004) evaluated the usefulness of LISS IV for coastal zone studies in the region of Okha, Gulf of Kachchh, India and found LISS IV data valuable in getting information on build-up area and high tide line with greater precision and suggested its use in the classification of the Indian coast for regulation at 1: 25000 scale. Study also recommended possible zonation for mangrove and coral reef by LISS IV, where LISS III data has showed its limitations.

Rajankar *et al*. (2004) demonstrated the usefulness of LISS IV for agriculture applications. They generated coastal landuse/cover map of Dahanu tehsil of Thane district, Maharashtra and observed that LISS IV clearly discriminated land use/cover classes like agriculture crop area, horticulture plantation, mangroves, mudflats, salt pans and wastelands. Another study showing application of LISS IV in agriculture was presented by Sesha Sai *et al*. (2004). They tried to assess potential of LISS IV in identification of intra field variability in crop field in ICRISAT farm near Hyderabad. They confirmed its potential to capture intra field variability in crop fields of size 1 ha, thus it can meet some of the essential requirements of the precision farming technology. Oza *et al*. (2004) further confirmed the effectiveness of LISS IV for agriculture studies and presented some limitations and recommendations after its comparison with LISS III in areas of Gandhinagar. They inferred that aggregate scene statistics of two sensors are comparable; information content of LISS IV red band is higher than that of LISS III; SWIR band in LISS III improves the crop separability; and the spectral discrimination with maximum likelihood is better with LISS III than with LISS IV, when the numbers of training classes are kept same. However, LISS IV detects larger number of cluster and identifies larger number of individual fields. This indicates that for optimal utilization of LISS IV data, other sets of classifiers such as object recognition have to be evaluated.

The LISS IV data found enormous utility in developmental planning and decision making activities pertaining to agriculture, land and water resource management, wasteland/watershed development, forestry, disaster management, infrastructure, and education by the Gujarat state as reported by Singh (2004). Digital GIS database developed by Gujarat used LISS IV for overlaying of the computerised cadastral maps which will allow information to become easily available like: parcel-wise information on land use/cover; agricultural use; cropping pattern; location of wells; forest type and status; land ownership; and infrastructure information. This information can be used for resource planning. For infrastructure planning, roads and individual habitation have been mapped using LISS IV. Mapping has been found to be feasible in plain areas but not in hilly areas. Creation of digital database and resource information system have facilitated the data utilisation and implementation for developmental planning by various government departments.

Sudhakar *et al*. (2004) studied the use of LISS IV for deriving information for forest resource management in Mudumalai Wildlife Sanctuary, Tamil Nadu. The study brought out the potential of LISS IV in delineation of small patches of semi-evergreen forest associated with riverine and moist deciduous forest. They could able to delineate five crown density levels which eliminated the limitation of LISS III-PAN merged data due to acquisition at different dates.

Besides above successful demonstrated ability of LISS IV in mapping required by different sectors, the present study has also aptly validated its enhanced capability in the field of mapping required for protected areas that too in an environmentally gradient complex landscape wherein diverse forests occur with small extent of interspersed numerous grasslands and swamps.

3.5.2 Lessons Learned and Future Prospective

Using a high resolution data and its application in land use/land cover mapping for protected area management has provided some following gainful experiences:

(a) Careful selection of timing of satellite data

In the present study, satellite data of later part of the year, especially October and November was found to be of good quality for interpretation. Initially to expedite the entire mapping process, few scenes of early months (March and April) were obtained for DNP to compensate for gap areas. Unfortunately, the hasty decision adversely affected the mapping accuracy for several vegetation types. During March and April, most tree species shed their leaves due to deciduous nature and this greatly affected the ability to interpret percentage canopy or species composition. Prominent management concerns in DNP and other LMU's require mapping of grasslands and wetlands. Till March, all grasslands are usually burned and wetlands get dried which affects their signature in satellite data and misinterpretation is likely to occur. Thus, the timing of the satellite data is of utmost importance in relation to the objectives of the study and management issues.

(b) Interpretation technique

The experience from the present study suggests that visual interpretation is a better methodology for extraction of information when dealing with high spatial resolution data. Many authors working with high spatial resolution data have made the similar recommendations (Welch *et al.*, 2002; Faour and Kheir, 2002). Welch *et al.* (2002) stressed that till now automated classification techniques do not match human interpreters in their ability to assess the colours, pattern, texture, context, height, shape, size and location that together make up the signature of a plant community.

(c) Classification and mapping should be done in sequence and not parallel

In the present study, classification and mapping of vegetation proceeded parallel, as the vegetation samples were being collected in the field; mapping was also simultaneously carried out. After the entire area got sampled, some of the land use/cover types were had to be refined several times. Thus, it is advisable to analyse the vegetation samples first and draft a classification, and start the mapping process in the end.

(d) Discussion forum to ensure information exchange between ecologists, mappers, and managers

Discussions between ecologists, mappers, and managers are critical at all stages of field work, classification and mapping towards developing a useful classification.

(e) Enhanced protocol for accuracy assessment

Accuracy assessment becomes a problem when large number of GPS coordinate points give false error. False error specifies a mismatch between polygon attenuated land use class on classified map and attribute of field collected GPS point. Error could be due to any of the reasons: (a) error in GPS field coordinates; (b) error in the attribute of polygon designating wrong land use class; (c) field site assessment area smaller than polygon minimum mapping unit. False errors seriously reduce the accuracy of classified maps. Better training in GPS points selection process is necessary to avoid the false errors.

Others issues that arose with the use of high resolution data were: several images were required to cover the large study area, which caused considerable problem in mosaicing adjoining images from different dates leading to increased error in georeferencing.

In gist, the present study based on land use and spatial patterns justified protection and management of each PAs i.e. constituent area or Land Management Unit (LMU) for conservation of native biodiversity. Study also supported the use of high resolution data for improved land use mapping in case of PAs.

Chapter 4

The Landscape – Forest Vegetation

4.1 Forest Vegetation

Tropical forests are the most ancient, the most diverse, and the most ecologically complex of land communities (Lewin, 1986; Laurance and Bierregaard, 1997; Mohanty *et al*., 2005). Forests are ever-changing assemblages of species shaped by climate and other physical factors. This is relevant in case of tropical deciduous forests as they occur under varied climatic conditions, but essentially with alternate wet and dry periods. The structure and composition of deciduous forests change with the length of wet period, amount of rainfall, latitude, longitude, and altitude (Shankar, 2001).

Vegetation, i.e. the community of plants occurring at a particular site, is an important feature of both natural and man-made habitats. The conditions of the vegetation in a stand, landscape or region is a production of the interplay of forces of disturbance and biotic development on a stage set by patterns and dynamics of climate, soil, and landforms (Hunter, 1999). The description of vegetation with or without concurrent recording of factors in the environment has played a major role in the development of the plant ecology and continues to be an important (Greig-Smith, 1983). According to Singh (1999), a considerable proportion of all ecological work in the past and to a large extent at present has been directed towards the description of vegetation.

Structure, composition, and function are the three important attributes of the vegetation communities (Timilsina *et al*., 2007). These attributes change in response to driving, abiotic and biotic variables. These variables and forest succession are responsible for both local (within stand) and landscape level variation in forest attributes, thereby producing spatial heterogeneity.

The diversity of trees is fundamental to total tropical forest biodiversity, because trees provide resources and habitats for almost all other forest species (Richards, 1952 and 1963; Hall and Swaine, 1976; Sutton *et al*., 1983; Mabberley, 1983; Longman and Jenik, 1987; Huston, 1994; Whitmore, 1998; Cannon *et al*., 1998; Huang *et al*., 2003). There are differences in species composition at all scales. Species composition is one of the major components of biologically spatial structure (Huang *et al*., 2003). Generally, vegetation structure along the forest interior-edge-exterior gradient changes from an assemblage of densely packed mature canopy and subcanopy trees in the interior to a more open, less dense stand at the edge, with a slight increase in small and large saplings closer to adjacent and abandoned pastureland (Oosterhoorn and Kappelle, 2000). Hence, the structure and composition of the vegetation reflect the ecosystem properties and ecological conditions of an area that form the bases for further scientific studies and management of an area (Lindenmayer and Franklin, 1997). The attributes of vegetation are also of major significance in animal ecology and wildlife management.

The length of monsoon, total rainfall, seasonal flooding and soil conditions, and other factors such as grazing, clearing for cultivation, burning, selective cutting, logging, and lopping have been considered as factors modifying vegetational composition and succession in the western *Terai* of Nepal (Dinerstein, 1979; Timilsina *et al*., 2007). Similarly, the forests in Indian *Terai* or specifically Dudhwa landscape also has long history of forest working, resource extraction by forest dwelling communities, flooding, burning, grazing, and land conversion for agriculture. Forests in Dudhwa landscape assume unusual significance for conservation despite they are the most used, altered and threatened ecosystems and vegetation has been greatly influenced and modified. Nevertheless, the conservation of plant diversity and habitats they make in Dudhwa landscape are essential for present and future use.

In general, present knowledge of forest structure, composition, and dynamics is highly inadequate. Quantitative forest vegetation assessments focussing on phytosociological patterns and other ecological studies on Indian deciduous forests are also not many (Shankar, 2001; Sukumar *et al*., 1992). Vegetation characteristics of Sal dominated forests in Central and Eastern Himalaya and Central India and other deciduous forests in India have been studied by few authors (Mohanty *et al*., 2003; Singh and Singh, 1992, Shankar, 2001; Sukumar *et al*. 1999, Shankar *et al*. 1998) and compared by Singh and Singh (1992) and Shankar (2001). Likewise, a few floristic studies conducted on Sal dominated forests inside protected areas located in Nepalese *Terai* and in Central Nepal have been reported by Dinerstein (1979), Shrestha and Jha (1997), Sharma (1999), and Web and Sah (2003). Timilsina *et al.* (2007) reported the community analysis of Sal forests in the western *Terai* of Nepal. Prominent ecological studies dealing with vegetation of tall grasslands in *Terai* are by Lehmkuhl (1989 and 1994), Peet (1997), Peet *et al.* (1999), and Mathur *et al.* (2003). Only a handful studies dealing with vegetation of Sal dominated forests and grasslands in Indian *Terai* are available. Pandey and Shukla (1999) assessed plant diversity and community patterns along the disturbance gradient in plantation forests of Sal in Gorakhpur Forest Division, eastern *Terai*. Shankar (2001) studied the floristic composition, tree regeneration and conservation status of rare species in Sal dominated lowland forests of Mahananda Sanctuary in the Eastern Himalaya and reported occurrence of far greater species richness in otherwise a seasonally dry, Sal forest. The only available detailed study on vegetation assessment in the context of Dudhwa landscape as already stated in the Chapter 2 is by Kumar *et al.* (2002). However, this study was confined to DNP, KWS, NKFD, and SKFD. KAT, a constituent unit of the present study site i.e. Dudhwa landscape could not be included by them as a part of investigation. Thus, the present investigation attempted to fill this gap in the context of KAT.

4.2 The Objectives

In light of the above description and land use/land cover patterns already described in Dudhwa landscape in the previous chapter, the present investigation aimed to provide important information on the structure of forests and grassland vegetation and plant composition in KAT. Specific objectives are to report on the floristic composition and structure of diverse forests and grasslands in KAT and to explore factors both anthropogenic and environmental that may be responsible for variation among different forest and grassland types. The study also intended to assess regeneration status of prominent tree species.

4.3 Methodology

The following section describes the field methodology employed in KAT, parameters assessed and vegetation analysis.

Field sampling: Details on reconnaissance and field sampling for vegetation classification have already been described along with the methodology on the land use/land cover mapping as presented in para 3.3.1 (b) of Chapter 3. Accordingly, 505 nested circular plots (10 m radius) were sampled for quantification of forest and grassland vegetation in KAT. Out of this, 432 plots were exclusively laid in woodland/forests while 73 plots were laid in grasslands.

At each sampled plot, individuals with >30 cm girth at breast height (GBH) and >3 m height were considered as trees and were enumerated in 10 m radius circular plot and their species and GBH at 1.35 m height above ground level was noted. Woody species with GBH < 30 cm, height < 3 m and those branching from the base of the stem were considered as shrubs and were enumerated in nested 5 m radius circular plot within the above large plot. The species were identified and their numbers of individuals were recorded. Also within this 5 m, tree species with individuals having GBH between >10 cm and < 30 cm were also noted and treated as sapling. For grasses and herbs, yet another 1 m×1 m nested quadrat was laid within above 5 m radius circular plot, and herb species and their number of individuals were recorded and in case of grasses only presence/absence of grass species was noted down.

Vegetation analysis: The field data collected was analyzed for frequency, density, and dominance/abundance of trees, shrubs, and herbs following Kent and Cooker (1994). The percentage frequency of occurrence in case of grass species was computed based on presence/absence data. The relative values of frequency, dominance, and density were used for determining Importance value Index (IVI) which is the sum of relative values of frequency, density and dominance (basal area) or abundance (shrub and herb) following Mishra (1968), Zhang and Cao (1995), and Kent and Cooker (1994).

The following formulae were used for analyses:

$$\textbf{\% Frequency} = \frac{\text{Total number of plots in which the species occurred}}{\text{Total number of plots sampled}} \times 100$$

$$\textbf{Density} = \frac{\text{Total number of individuals of a species in all sampled plots}}{\text{Total area of all sampled plots (ha)}}$$

$$\textbf{Abundance} = \frac{\text{Total number of individuals of a species in all plots}}{\text{Total number of plots in which the species occurred}}$$

$$\textbf{Dominance} = \frac{\text{Total basal area of a species in all sampled plots}}{\text{Total area of all sampled plots (ha)}}$$

Diversity Indices: Diversity of communities can be assessed using 'species richness' (measure of total number of species in a sampling area), species abundance model or evenness (how the abundance data are distributed among the species) and indices based on the proportioned abundance of the species. Over the years a number of indices have been proposed for characterizing species richness and evenness. Such indices are termed as richness and evenness indices. indices and their formulae which are used in the present study are explained below:

Species Richness: The number of species in a community or in a sampling area is referred as species richness.

Margalef (1958) has given an index for species richness:

$$\textbf{Margalef Index R} = \frac{s-1}{\ln(n)}$$

Where, s = the total number of species in a community; n = sampling points

'Higher the value of R means greater species richness'.

Species Evenness or Equitability: Evenness refers to how the species abundances (e.g., the number of individuals, biomass, cover etc.) are distributed among the species. Shannon's Index (H') was used in the present study.

Shannon's Index (H'): The Shannon Index (H') has probably been the most widely used index in community ecology. It is based on information theory (Shannon and Wiener, 1949) and is a measure of the average degree of "uncertainty" in predicting to what species an individual chosen at random from a collection of s species and n individuals will belong. This average uncertainty increases as the number of species increases and as the distribution of individuals among the species becomes even. The Shannon diversity index is calculated from the formula:

$$\textbf{Diversity H'} = \sum_{i=1}^{s} p_i \ln p_i$$

where s = the number of species

p_i = the proportion of individuals or abundance of the ith species expressed as a proportion of total cover

ln = log base_n

The value of the index usually lies between 1.5 and 3.5. Maximum the value of H' means all s species are represented by the same number of individuals, that is, a perfectly even distribution of abundance.

4.4 Results

The land use/land cover classes highlighting four types of Sal forests, seven other forests types, two types of plantation, and two grassland classes have already been described in the previous Chapter (para 3.4.1). The following section firstly presents an overall structure and plant species composition for KAT, and secondly describes plant diversity for each vegetation type. This is followed by population structure of trees and regeneration status of three prominent tree species. Lastly, a presentation exclusively dealing with the structure and composition of grasslands in Dudhwa landscape is being made.

4.4.1 Vegetation Structure and Composition in Overall KAT

Structure and species composition of tree, shrub, herb, grass, and fern habits in KAT are presented below one by one.

(a) Overall plant diversity

The analysis of 505 vegetation plots sampled in different forests and grasslands of KAT revealed a diversity of 142 plant species. This included 58 tree, 32 shrub, 30 herb, 15 grass, 2 sedge and 5 fern species representing 56 families and 123 genera.

***Tree diversity*:** A total of 3,074 individuals belonging to 58 tree species were enumerated in 505 sampled plots covering an area of 15.85 ha (Table 4.1). Tree species recorded in KAT represented 30 families and 51 genera. The *Mallotus philippensis* recorded the highest value of percentage frequency. The species occurred in as many as 49.1% plots sampled followed by Sal, Teak, and *Syzygium cumini* with frequency values, being 35.2% and 22.5%, and 19.6%, respectively. As many as 32 tree species reported % frequency less than 1 indicating extreme narrow distribution and occurrence. Further, out of 58 recorded tree species, only 6 species obtained frequency value more than 10%. Beside four tree species already listed above, *Acacia catechu* and

Table 4.1 - Tree Species with Values of Their Frequency of Occurrence, Density, Basal Area and IVI in KAT

Tree species	Family	Frequency (%)	Density (ha^{-1})	Basal Area (m^2/ha)	IVI
Shorea robusta	Dipterocarpaceae	35.2	33.1	7.9	72.1
Mallotus philippensis	Euphorbiaceae	49.1	50.4	1.2	52.8
Tectona grandis	Verbanaceae	22.5	30.9	2.1	36.1
Syzygium cumini	Myrtaceae	19.6	13.0	1.3	21.5
Terminalia alata	Combretaceae	12.2	7.6	1.4	16.5
Acacia catechu	Mimosaceae	10.8	7.9	0.3	10.5
Lagerstroemia parviflora	Lythraceae	10.3	4.3	0.3	8.3
Trewia nudiflora	Euphorbiaceae	7.9	5.7	0.3	8.2
Bombax ceiba	Bombacaceae	4.1	3.0	0.8	7.4
Aegle marmelos	Rutaceae	7.1	5.1	0.2	6.7
Mitragyna parvifolia	Rubiaceae	7.5	4.0	0.2	6.5
Ehretia laevis	Ehretiaceae	6.9	4.4	0.1	5.9
Haldina cordifolia	Rubiaceae	3.5	1.3	0.4	4.6
Ficus racemosa	Moraceae	3.5	1.9	0.3	4.4
Dalbergia sissoo	Fabaceae	3.9	2.5	0.2	4.3
Diospyros exsculpta	Ebenaceae	4.1	2.0	0.2	3.8
Lannea coromandelica	Anacardiaceae	2.3	1.0	0.2	2.7
Eucalyptus citriodora	Myrtaceae	1.5	1.9	0.1	2.4
Schleichera oleosa	Sapindaceae	2.3	0.8	0.15	2.1
Streblus asper	Moraceae	2.5	1.4	0.05	2.0
Bridelia squamosa	Euphorbiaceae	1.9	0.7	0.08	1.6
Terminalia arjuna	Combretaceae	0.9	1.5	0.08	1.6
Litsea glutinosa	Lauraceae	2.1	0.7	0.06	1.5
Ficus hispida	Moraceae	1.9	1.0	0.04	1.5
Drypetes roxburghii	Euphorbiaceae	0.9	0.4	0.15	1.4
Bauhinia racemosa	Caesalpiniaceae	1.7	0.6	0.02	1.2
Grewia tiliafolia	Tiliaceae	1.3	0.5	0.04	1.0
Dillenia pentagyna	Dilleniaceae	1.1	0.5	0.04	0.9
Albizia procera	Mimosaceae	0.5	0.4	0.08	0.9
Cassia fistula	Caesalpiniaceae	0.9	0.3	0.04	0.7

Contd.

Table 4.1 Contd…

Tree species	Family	Frequency (%)	Density (ha^{-1})	Basal Area (m^2/ha)	IVI
Litsea monopetala	Lauraceae	0.79	0.32	0.03	0.62
Albizia chinensis	Mimosaceae	0.79	0.38	0.02	0.60
Ficus rumphii	Moraceae	0.59	0.19	0.04	0.53
Madhuca longifolia	Sapotaceae	0.79	0.25	0.01	0.53
Miliusa velutina	Annonaceae	0.79	0.25	0.01	0.51
Erioglossum rubiginosum	Sapindaceae	0.59	0.19	0.02	0.43
Pterocarpus marsupium	Fabaceae	0.20	0.19	0.04	0.39
Butea monosperma	Fabaceae	0.59	0.19	0.01	0.37
Ziziphus mauritiana	Rhamnaceae	0.59	0.19	0.00	0.36
Salix tetrasperma	Salicaceae	0.40	0.25	0.01	0.32
Cordia dichotoma	Ehretiaceae	0.40	0.13	0.01	0.27
Buchanania lanzan	Anacardiaceae	0.40	0.13	0.01	0.25
Catunaregam uliginosa	Rubiaceae	0.40	0.13	0.00	0.24
Wendlandia heynei	Rubiaceae	0.20	0.06	0.02	0.20
Ficus religiosa	Moraceae	0.20	0.06	0.01	0.18
Grewia elastica	Tiliaceae	0.20	0.06	0.01	0.16
Melia azedarach	Meliaceae	0.20	0.06	0.01	0.16
Stereospermum chelonoides	Bignoniaceae	0.20	0.06	0.01	0.16
Azidarachta indica	Meliaceae	0.20	0.06	0.01	0.15
Emblica officinalis	Euphorbiaceae	0.20	0.06	0.01	0.15
Toona ciliata	Meliaceae	0.20	0.06	0.01	0.15
Barringtonia acutangula	Lecythidaceae	0.20	0.06	0.01	0.14
Celtis tetrandra	Urtiacaceae	0.20	0.06	0.00	0.13
Holarrhena pubescens	Apocynaceae	0.20	0.06	0.00	0.13
Derris indica	Fabaceae	0.20	0.06	0.00	0.12
Glochidion assamicum	Euphorbiaceae	0.20	0.06	0.00	0.12
Kydia calycina	Malvaceae	0.20	0.06	0.00	0.12
Murraya koenigii	Rutaceae	0.20	0.06	0.00	0.12
Total			**193.9**	**19.6**	

Lagerstromea parviflora were two other tree species obtaining values of frequency as 10.8% and 10.3%, respectively.

The overall tree density computed for KAT was 193.9 individuals/ha. The density values of 58 tree species ranged from 0.06 individuals/ha to 50.4 individuals/ha. The highest tree density was recorded by *Mallotus philippensis* being 50.4 individuals/ha followed by Sal (33.1 individuals/ha) and Teak (30.9 individuals/ha). As many as 63.7% or 37 tree species obtained density value less than 1 individuals/ha. The overall basal area of all trees across all the sampled plots was 19.6 sq m/ha, the maximum value of 7.93 sq m/ha was registered by Sal followed by Teak (2.1 sq m/ha). Other species which contributed significantly to basal area were *T.alata* (1.4 sq m/ha), *Syzygium cumini* (1.3 sq m/ha), and *Mallotus philippensis* (1.2 sq m/ha).

The values of IVI for 58 tree species ranged from 0.1 to 72.1. The highest value of 72.1 was obtained by Sal followed by *Mallotus philippensis* (52.8). Prominent other tree species based on IVI values were *Tectona grandis* (36.1), despite an exotic to the area, *Syzygium cumini* (21.5), and *T.alata* (16.5). In all, 42 species registered value of IVI less than 3.

***Shrub diversity*:** A total of 32 shrub species were observed in 505 sampled plots laid in KAT (Table 4.2). They represented 19 families and 30 genera. The values of frequency of occurrence for all species ranged from 0.2% to 53.4%. The maximum value of % frequency, being 53.4 was registered by *Glycosmis pentaphylla*, the next highest % frequency values in order were 50.8% and 47.5% as registered by *Clerodendrum viscosum* and *Murraya koenigii*, respectively. Other common species were *Callicarpa macrophylla* and *Ichnocarpus frutescens* with 38.2% and 21.1%, values respectively. As many as 20 species or 62.5% shrub species obtained low values of % frequency less than 5. The overall shrub density computed to 7,345 individuals/ha with maximum density of 2356.7 individuals/ha being represented by *Tiliacora acuminata* followed by 1,463.8 individuals/ha value in case of *Glycosmis pentaphylla*. Important browsed species like *Helicteres isora* and *Carissa opaca*, occurred in lower densities.

The *Tiliacora acuminata* obtained the highest abundance value of 41.3 followed by *Clerodendrum viscosum* and *Glycosmis pentaphylla*, both obtained nearly same abundance values of 21.8 and 21.3 respectively (Table 4.2). The *Tiliacora acuminata* registered the highest IVI value of 61.0 followed by *Glycosmis pentaphylla* (43.9).

Herb diversity**:** In all, 30 species of herbs were recorded in 505 sampled plots. They were represented by 21 families and 29 genera. The *Curculigo orchioides* occurred in maximum number of sampled plots and thus recorded the highest value of % frequency being 12.6% followed by *Achyranthes aspera* (9.3 %). About 15 or 50% of herb species, recorded value of % frequency <1%. The overall herb density was found to be 65,340 individuals/ha. The maximum density of 9,460 individuals/ha was represented by *Curculigo orchioides*, followed by *Oxalis corniculata* with 9,400 individuals/ha.

Dicliptera roxburghiana was found to be most abundant herb as it recorded maximum abundance value of 46.6, followed by value of 35 obtained by *Ageratum conyzoides.* The maximum IVI value of 33.3 was obtained by *Curculigo orchioides*. Other prominent herbs with high value of IVI were *Oxalis corniculata* (27.9)*, Achyranthes aspera* (25.9), and *Dicliptera roxburghiana* (22.0).

Grass diversity**:** Fifteen species of grasses were recorded in KAT in 505 plots across different woodland and grassland (Table 4.4). They were represented by 1 family and 13 genera*. Cyrtococcum patens* and *Imperata cylindrica* both shared the maximum %frequency value, being 28.3%. This was followed by *Desmostachya bipinnata* with frequency of occurrence being 23.9%. Other important species on the basis of higher % frequency of occurrence were: *Vetiveria zizaniodes* (11.6%)*, Cynodon dactylon* (8.3%)*, and Apluda mutica* (7.1%). Three species of genus *Saccharum* registered value <5%.

Table 4.2 - Shrub Species with Values of Frequency of Occurrence, Density, Abundance, and IVI in KAT

Shrub species	Family	Frequency (%)	Density (ha^{-1})	Abundance	IVI
Tiliacora acuminata	Menispermaceae	44.3	2356.7	41.3	61.0
Glycosmis pentaphylla	Rutaceae	53.4	1463.8	21.3	43.9
Clerodendrum viscosum	Verbenaceae	50.8	1431.5	21.8	42.9
Murraya koenigii	Rutaceae	47.5	534.3	8.7	24.7
Callicarpa macrophylla	Verbenaceae	38.2	417.8	8.5	20.2
Ichnocarpus frutescens	Apocynaceae	21.1	290.3	10.6	14.3
Flemingia chappar	Fabaceae	15.4	217.8	10.9	11.7
Lantana camara	Verbenaceae	5.9	131.5	17.2	10.1
Calamus tenuis	Arecaceae	5.5	117.3	16.4	9.5
Ziziphus maurtiana	Rhamnaceae	13.0	148.3	8.8	9.2
Acacia sinuata	Mimosaceae	18.8	82.1	3.4	8.0
Barleria cristata	Acanthaceae	0.2	4.3	17.0	6.6
Ziziphus oenoplia	Rhamnaceae	0.9	17.5	13.8	5.8
Putranjiva roxburghii	Euphorbiaceae	5.7	50.3	6.8	5.0
Ipomea carnea	Convolvulaceae	0.7	11.2	11.0	4.5
Polyalthia suberosa	Annonaceae	4.9	35.3	5.5	4.0
Helicteres isora	Sterculiaceae	0.7	6.3	6.2	2.7
Carissa opaca	Asclepiadaceae	3.5	12.2	2.6	2.2
Sesbania bispinosa	Fabaceae	0.9	4.5	3.6	1.7
Sterculia villosa	Sterculiaceae	0.4	2.0	4.0	1.6
Smilax perfoliata	Smilacaceae	0.2	1.0	4.0	1.6
Asparagus adscendens	Liliaceae	0.5	2.0	2.6	1.2
Colebrookea oppositifolia	Lamiaceae	0.2	0.7	3.0	1.2
Calotropis procera	Asclepiadaceae	0.7	2.0	2.0	1.0
Clausena pentaphylla	Rutaceae	0.5	1.5	2.0	0.9

Contd….

Table 4.2 Contd…

Shrub species	Family	Frequency (%)	Density (ha^{-1})	Abundance	IVI
Phoenix acaulis	Arecaceae	0.2	0.5	2.0	0.8
Desmodium gangeticum	Fabaceae	0.4	0.5	1.0	0.5
Erthyrina respinata	Fabaceae	0.2	0.2	1.0	0.4
Oroxylum indicum	Bignoniaceae	0.2	0.2	1.0	0.4
Tamarix dioica	Tamariacaceae	0.2	0.2	1.0	0.4
Vallaris solanacea	Apocynaceae	0.2	0.2	1.0	0.4
Ziziphus rugosa	Rhamnaceae	0.2	0.2	1.0	0.4
Total			**7345**	**261.74**	

***Fern and sedge diversity*:** Five species of fern and two species of sedge were recorded in 505 plots across different woodland and grassland in KAT. Species of fern were represented by 5 family and 5 genera whereas sedges were represented by 1 family and 1 genus (Table 4.5).

4.4.2 Vegetation Structure and Species Composition

Species composition for tree layer and their IVI values are presented below for each vegetation type one by one. Plate 4.1 to 4.3 presents the photographs of few vegetation types. Number of tree species specific to each vegetation type ranged from 6 to 40 (Table 4.6). The lowest number of tree species was recorded in the case of *Aegle* Forest and Grassland while maximum species in case of Mixed Deciduous Forest. Interestingly, Teak Plantation recorded 23 species, third highest number of species in all forest types, albeit being an exotic and plantation species. Among Sal Forest types, Moderately Dense Sal Forest represented maximum number of species followed by Open Sal Forest, Sal Mixed Forest, and Dense Sal Forest.

Table 4.3 - Herb Species with Values of Frequency of Occurrence, Density, Abundance, and IVI in KAT

Herb species	Family	Frequency (%)	Density (ha^{-1})	Abundance	IVI
Curculigo orchioides	Amaryllidaceae	12.6	9460	7.3	33.3
Oxalis corniculata	Oxalidaceae	6.5	9400	14.2	27.9
Achyranthes aspera	Amaranthaceae	9.3	7320	7.7	25.9
Dicliptera roxburghiana	Acanthaceae	0.5	2800	46.6	22.0
Sida rhombifolia	Malvaceae	7.7	4860	6.2	19.5
Curcuma amada	Zingiberaceae	2.7	5260	18.7	18.4
Solanum surattense	Solanaceae	6.3	4280	6.6	17.0
Cissampelos pareira	Menispermaceae	6.1	4140	6.6	16.6
Piper longum	Piperaceae	3.9	4580	11.4	16.2
Ageratum conyzoides	Asteraceae	0.4	1400	35.0	15.4
Sagittaria trifolia	Alismataceae	0.2	600	30.0	12.1
Cynoglossum zeylanicum	Boraginaceae	1.3	2380	17.0	11.6
Cannabis sativa	Cannabaceae	1.3	1720	12.2	8.8
Rungia pectinata	Acanthaceae	3.7	1580	4.1	8.7
Bauhinia vahlii	Caesalpiniaceae	3.5	1440	4.0	8.2
Blumea laciniata	Asteraceae	3.5	960	2.6	7.0
Bridelia stipularis	Euphorbiaceae	1.3	1220	8.7	6.8
Sida cordata	Malvaceae	0.5	600	10.0	5.3
Leucas cephalotes	Lamiaceae	0.5	500	8.3	4.5
Phumaris rubra	Apocynaceae	1.9	260	1.3	3.4
Parthenium hysterophorus	Asteraceae	0.5	220	3.6	2.4
Asphodelus tenuifolius	Liliaceae	0.7	120	1.5	1.7
Eclipta prostrata	Asteraceae	0.4	60	1.5	1.1
Cirsium arvense	Asteraceae	0.2	40	2.0	1.0
Ziziphus rugosa	Rhamnaceae	0.4	40	1.0	0.93
Amaranthus spinous	Amaranthaceae	0.2	20	1.0	0.6
Mimosa pudica	Mimosaceae	0.2	20	1.0	0.6
Nelsonia canescens	Acanthaceae	0.2	20	1.0	0.6
Vernonia cinerea	Asteraceae	0.2	20	1.0	0.6
Vicia sativa	Fabaceae	0.2	20	1.0	0.6
Total			**65340**	**274**	

Table 4.4 - Grass Species with Values of Frequency of Occurrence in KAT

Grass species	Family	Frequency (%)
Cyrtococcum patens	Poaceae	28.3
Imperata cylindrica	Poaceae	28.3
Desmostachya bipinnata	Poaceae	23.9
Vetiveria zizaniodes	Poaceae	11.6
Cynodon dactylon	Poaceae	8.3
Apluda mutica	Poaceae	7.1
Saccharum bengalense	Poaceae	4.5
Saccharum spontaneum	Poaceae	4.5
Saccharum narenga	Poaceae	3.1
Bothriochloa pertusa	Poaceae	2.3
Cymbopogon jwarancusa	Poaceae	1.1
Paspalum distichum	Poaceae	0.9
Phragmites karka	Poaceae	0.7
Schlerostachya fusca	Poaceae	0.4
Eulaliopsis binata	Poaceae	0.2

Table 4.5 – Fern and Sedge Species in KAT

Fern Species	Family
Adiantum lunalatum	Adiantaceae
Ceratopteris thalicteroides	Parkeriaceae
Diplazium esculentum	Athyriaceae
Lygopodium flexuosum	Lygodiaceae
Pteris vittata	Pteridaceae
Sedge Species	
Cyperus brevifolius	Cyperaceae
Cyperus rotundus	Cyperaceae

Plate 4.1 – Different Vegetation Types in KAT

The Dense Sal Forest, one of the characteristics features of this tract, occurred on well drained higher alluvial terraced with loamy soil. Co-associates were *Terminalia alata*, *Syzygium cumini*, *Ehretia laevis*, and *Lagerstroemia parviflora*.

Tropical Semi-Evergreen Forest occurred on clay and humus rich soil along perennial streams, characterised by presence of cane, ferns and several climbers. Prominent tree species: *Trewia nudiflora*, *Mallotus philippensis*, and *Syzygium cumini*.

Tropical Seasonal Swamp Forest were found in swampy depressions along streams in water logged areas. *Syzygium cumini* dominated this forest type. *Trewia nudiflora*, *Ficus racemosa*, and *Acacia catechu* were other prominent co-associates.

Plate 4.2 – Different Vegetation Types in KAT

Lowland Grasslands are found in low lying areas along rivers and streams. The prominent species were *Phragmites karka*, *Saccharum narenga*, *Saccharum spontaneum*, and *Schlerostachya fusca*.

Upland Grasslands were found as grassy blanks on well drained soils within forests. The dominant grasses included *Cyrtococcum patens*, *Desmostachya bipinnata*, *and Imperata cylindrica*. *Bombax ceiba*, *Dalberbia sissoo*, *Acacia catechu*, are occasionaly seen.

***Aegle* Forest are represented by pure stand of *Aegle marmelos* but at many places get mixed with *Diospyros exsculpta*, *Acacia catechu*, *Tectona grandis*. They are confined to the eroded higher areas surrounding river beds.**

Plate 4.3 – Different Plantations in KAT

Eucalyptus citriodora plantations were widely planted during the period of active forest working. They were planted along railway line, roads and in 'grassy blanks'.

Khair *(Acacia catechu)* is planted on new sandy alluvium deposited by rivers.

Bamboo *(Dendrocalamus strictus)* has also been planted along with *Eucalyptus*.

Table 4.6 – Tree Species in Different Vegetation Types in KAT (number of plots = 505)

Tree Species	Dense Sal Forest	Moderately Dense Sal Forest	Sal Mixed Forest	Open Sal Forest	Mixed Deciduous Forest	TSE	TSSF	*Terminalia alata* Forest	Khair & Sissoo Forest	*Aegle* Forest	Teak Plantation	Open Plantations	Grassland	Total
Azidrachta indica										*				1
Barringtonia acutangula					*									1
Buchanania lanzan					*									1
Butea monosperma					*									1
Celtis tetrandra		*												1
Derris indica					*									1
Emblica officinalis											*			1
Erioglossum rubiginosum		*												1
Ficus religiosa					*									1
Glochidion assamicum			*											1
Grewia elastica						*								1
Holarrhena antidysenterica													*	1
Kydia calycina		*												1
Litsea monopetala					*									1
Melia azedarach				*										1
Murraya koenigii					*									1
Pterocarpus marsupium	*													1
Stereospermum chelonoides					*									1
Toona ciliata											*			1
Wendlandia heynei					*									1
Albizia chinensis						*		*						2
Catunaregam uliginosa					*				*					2
Cordia dichotoma									*	*				2
Drypetes roxburghii					*	*								2
Ficus rumphii	*	*												2
Salix tetrasperma					*		*							2
Ziziphus mauritiana					*	*								2
Albizia procera					*	*	*							3

Contd…

Table 4.6 Contd….

Tree Species	Dense Sal Forest	Moderately Dense Sal Forest	Sal Mixed Forest	Open Sal Forest	Mixed Deciduous Forest	TSE	TSSF	*Terminalia alata* Forest	Khair & Sissoo Forest	*Aegle* Forest	Teak Plantation	Open Plantations	Grassland	Total
Cassia fistula	*	*			*									3
Eucalyptus citriodora					*						*	*		3
Grewia tiliafolia					*	*					*			3
Miliusa velutina		*									*	*		3
Terminalia arjuna			*			*						*		3
Bombax ceiba					*	*	*						*	4
Dillenia pentagyna			*	*				*			*			4
Diospyros exsculpta				*	*			*		*				4
Madhuca longifolia	*		*	*	*									4
Bauhinia racemosa					*	*	*	*			*			5
Ficus hispida		*		*	*	*					*			5
Litsea glutinosa	*	*	*	*							*			5
Dalbergia sissoo					*	*			*		*	*	*	6
Ficus racemosa		*			*	*	*		*			*		6
Lannea coromandelica		*		*	*		*	*			*			6
Streblus asper		*	*	*	*	*	*							6
Terminalia alata	*	*		*	*			*			*			6
Bridelia squamosa		*	*	*	*	*			*		*			7
Ehretia laevis	*	*		*	*		*	*			*			7
Schleichera oleosa		*	*	*	*	*		*			*			7
Trewia nudiflora	*				*	*	*		*		*	*		7
Aegle marmelos			*	*	*	*	*	*		*	*			8
Haldinia cordifolia	*		*	*	*	*	*		*			*		8
Shorea robusta	*	*	*	*	*		*	*			*			8
Acacia catechu		*			*	*	*		*	*	*	*	*	9
Mitragyna parvifolia	*	*	*	*	*	*	*	*			*			9
Tectona grandis	*	*		*	*	*		*		*	*	*	*	10
Lagerstroemia parviflora	*	*	*	*	*	*	*	*			*	*	*	11
Mallotus philippensis	*	*	*	*	*	*	*	*	*		*	*		11
Syzygium cumini	*	*	*	*	*	*	*	*	*		*	*		11
Total Species	15	22	16	20	40	24	17	15	10	6	23	12	6	

Out of 58 tree species, 23 species were found to be just confined to any one vegetation type. Three species *viz*. *Lagerstroemia parviflora*, *Mallotus philippensis*, and *Syzygium cumini* were common to almost all vegetation types. *Lagerstroemia parviflora* was absent in *Aegle* Forest and Khair and Sissoo Forest whereas *Mallotus philippensis* and *Syzygium cumini* could not be recorded in *Aegle* Forest and grasslands.

(a) Dense Sal Forest

A total of 15 tree species were recorded in this vegetation type (Table 4.7 and Plate 4.1). The maximum value of frequency of occurrence, being 96.3% was also shown by Sal. Another species which showed the prominent occurrence was *Mallotus philippensis* which occurred in 48.1% of the sampled plots. The overall tree density for Dense Sal Forests was 291.6 individuals/ha with Sal having the highest density of 198.8 individuals/ha and IVI of 182.0 followed by *Mallotus philippensis* with 32.1 individuals/ha as density and IVI of 31.1. The total basal area of all trees enumerated was 30.8 sq m/ha with major contribution of 23.9 sq m/ha by Sal. The IVI values varied from 1.8 to 182.0 for various tree species.

(b) Moderately Dense Sal Forest

Twenty two tree species were recorded in this class (Table 4.8). The highest frequency value of 96% was shown by Sal. Other species with high % frequency were *Mallotus philippensis* and *Terminalia alata* with values of 78% and 28%, respectively. The total tree density in this vegetation type was 251.9 individuals/ha with maximum of 105.7 individuals/ha being represented by Sal followed by *Mallotus philippensis* with 81.5 individuals/ha. The total basal area in this type of forest was 58.2 sq m/ha with again maximum contribution by Sal. Other species which contributed to basal area were *Mallotus philippensis* and *Terminalia alata*. The IVI values for 22 recorded tree species in this type varied from 0.9 to 145.7.

Table 4.7 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Dense Sal Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Shorea robusta	96.3	198.8	0.4	182.0
Mallotus philippensis	48.1	32.1	2.7	31.1
Terminalia alata	33.3	14.2	0.0	26.1
Syzygium cumini	33.3	20.2	0.1	23.1
Lagerstroemia parviflora	14.8	4.7	0.2	8.2
Pterocarpus marsupium	3.7	3.5	0.2	5.1
Trewia nudiflora	7.4	3.5	1.1	4.6
Cassis fistula	3.7	2.3	0.0	3.5
Tectona grandis	3.7	3.5	0.0	3.1
Haldinia cordifolia	3.7	2.3	0.0	2.9
Ficus rumphii	3.7	1.1	0.6	2.3
Ehretia laevis	3.7	1.1	23.9	1.9
Madhuca longifolia	3.7	1.1	0.3	1.8
Mitragyna parvifolia	3.7	1.1	0.1	1.8
Litsea glutinosa	3.7	1.1	0.7	1.8

(c) Sal Mixed Forest

A total of 16 tree species were recorded in this type. Sal represented the maximum frequency value of 89.4% followed by *Mallotus philippensis* and *Mitragyna parvifolia* (Table 4.9). The overall tree density of 184.7 individuals/ha was recorded. Sal dominated this Sal type with maximum density 71.1 individuals/ha and IVI value of 136.4. The total basal area in this Sal type was 41.6 sq m/ha with again major contribution of about 28.3 sq m/ha by Sal followed by *Syzygium cumini*. The IVI values for all recorded species varied from 2.7 to 136.4. The lowest value was in case of *Dillenia pentagyna* and *Glochidion assamicum* while highest IVI was registered by Sal.

Table 4.8 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Moderately Dense Sal Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Shorea robusta	96.00	105.73	21.87	145.78
Mallotus philippensis	78.00	81.53	1.90	63.76
Terminalia alata	28.00	15.92	2.78	24.57
Syzygium cumini	22.00	14.01	1.13	16.38
Lagerstroemia parviflora	16.00	5.10	0.20	7.81
Litsea glutinosa	12.00	4.46	**0.18**	6.44
Tectona grandis	6.00	5.10	0.19	4.59
Ehretia laevis	8.00	3.18	0.09	4.12
Acacia catechu	8.00	3.18	0.08	4.11
Erioglossum rubiginosum	6.00	1.91	0.18	3.27
Mitragyna parvifolia	2.00	0.64	0.55	2.74
Ficus rumphii	4.00	1.27	0.28	2.72
Schleichera oleosa	4.00	1.27	0.07	2.03
Cassia fistula	4.00	1.27	0.05	1.97
Ficus racemosa	2.00	1.91	0.17	1.96
Miliusa velutina	4.00	1.27	0.03	1.90
Streblus asper	2.00	0.64	0.06	1.11
Lannea coromandelica	2.00	0.64	0.02	0.98
Celtis tetrandra	2.00	0.64	0.02	0.98
Bridelia squamosa	2.00	0.64	0.02	0.96
Kydia calycina	2.00	0.64	0.01	0.92
Ficus hispida	2.00	0.64	0.00	0.91

(d) Open Sal Forest

The overall density of 20 recorded tree species in this vegetation type was about 198.7 individuals/ha. The maximum value of frequency, being 77.6% was registered by Sal which was having negligible difference from next highest frequency value of *Mallotus philippensis* i.e. 75.0% (Table 4.10). The maximum density of 73.9 individuals/ha was shown by *Mallotus philippensis* followed by 41.1 individuals/ha value obtained by Sal. Although *Mallotus philippensis* was having maximum density value and high % frequency but Sal still topped the IVI list with a value of 111.1 as compared to value of 67.8 in case of *Mallotus philippensis* due to its high basal area of 65.0 sq m/ha. The values of IVI varied from 0.6 to 111.1.

Table 4.9 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Sal Mixed Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Shorea robusta	89.47	71.19	28.37	136.41
Mallotus philippensis	52.63	40.68	0.88	41.68
Syzygium cumini	31.58	11.86	4.89	28.67
Mitragyna parvifolia	36.84	18.64	1.22	25.29
Terminalia alata	10.53	6.78	2.18	12.40
Haldinia cordifolia	10.53	3.39	1.57	9.10
Streblus asper	10.53	6.78	0.44	8.24
Aegle marmelos	10.53	5.08	0.16	6.64
Lagerstroemia parviflora	10.53	3.39	0.34	6.17
Litsea glutinosa	5.26	1.69	0.91	4.86
Bridelia squamosa	5.26	3.39	0.22	4.11
Schleichera oleosa	5.26	3.39	0.20	4.06
Diospyros exscupta	5.26	3.39	0.11	3.86
Madhuca longifolia	5.26	1.69	0.16	3.06
Dillenia pentagyna	5.26	1.69	0.02	2.72
Glochidion assamicum	5.26	1.69	0.02	2.72

(e) Mixed Deciduous Forest

The Mixed Deciduous Forest included the highest number of tree species i.e. 40 with *Mallotus philippensis* being the dominant one (Table 4.11). Sal showed its most dominance feature based on IVI in previous four Sal forest types. However, in case of Mixed Deciduous Forest, Sal ranked at 22nd in a list of 40 tree species. The maximum value of % frequency was obtained by *Mallotus philippensis*, being 73.9% followed by *Syzygium cumini* (21.9%) and *Acacia catechu* (21.9%). The overall tree density was 217.9 individuals/ha with *Mallotus philippensis* showing the maximum density of 89.0 individuals/ha followed by *Ehretia laevis* which showed much less value of just 14.4 individuals/ha. The value of total basal area in this type was 20.2 sq m/ha with maximum value of 3.6 sq m/ha registered by *Bombax ceiba*. This was followed by *Mallotus philippensis* with a value 2.9 sq m/ha. The IVI values ranged from 0.6 to 79.0. *Mallotus philippensis* recorded the maximum IVI followed by *Bombax ceiba* (26.7) and *Syzygium cumini* (23.3).

Table 4.10 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Open Sal Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Shorea robusta	77.63	41.18	16.84	110.77
Mallotus philippensis	75.00	73.95	1.56	67.77
Tectona grandis	25.00	25.21	0.97	24.59
Syzygium cumini	27.63	13.45	2.04	23.63
Terminalia alata	14.47	6.30	1.66	14.27
Mitragyna parvifolia	19.74	9.66	0.64	13.79
Lagerstroemia parviflora	15.79	8.40	0.66	11.93
Ehretia laevis	15.79	7.98	0.27	10.21
Aegle marmelos	11.84	5.04	0.41	7.98
Haldinia cordifolia	2.63	0.84	0.45	3.02
Diospyros exscupta	3.95	1.26	0.13	2.42
Bridelia squamosa	2.63	1.26	0.16	2.12
Schleichera oleosa	2.63	0.84	0.03	1.39
Streblus asper	2.63	0.84	0.02	1.37
Lannea coromandelica	1.32	0.42	0.10	1.02
Melia azedarach	1.32	0.42	0.06	0.86
Dillenia pentagyna	1.32	0.42	0.03	0.75
Madhuca longifolia	1.32	0.42	0.02	0.71
Litsea glutinosa	1.32	0.42	0.01	0.70
Ficus hispida	1.32	0.42	0.01	0.68

(f) Tropical Semi-Evergreen Forest

A total of 24 tree species were reported in this vegetation type with *Trewia nudiflora* showing its dominance with maximum IVI value of 57.4. *Trewia nudiflora* also obtained the maximum value of frequency of occurrence, being 46.8% and registered basal area of 3.2 sq m/ha (Table 4.12 and Plate 4.1). The total tree density in this vegetation type was 221 individuals/ha. The maximum density of 42 individuals/ha was contributed by *Trewia nudiflora* followed by *Mallotus philippensis* (37 individuals/ha). The total basal area in this vegetation type was 14.5 sq m/ha. After *Trewia nudiflora*, the next almost equal contribution to basal area was made by *Bombax ceiba*, being 3.0 sq m/ha. Other important species in this vegetation type with high and near equal IVI were *Syzygium cumini* (37.9), *Acacia catechu* (35.0), *Mallotus philippensis* (34.6), and *Bombax ceiba* (30.2).

(g) Tropical Seasonal Swamp Forest

This vegetation type was represented by 17 tree species with *Syzygium cumini* being the dominant one with maximum IVI value of 115.5 (Table 4.13 and Plate 4.1). The maximum value of frequency, being 83.3% was also obtained by *Syzygium cumini* followed by *Trewia nudiflora* (33.3%). The overall tree density was 183.9 individuals/ha with maximum representation by *Syzygium cumini* (96.4 individuals/ha) followed by *Trewia nudiflora* (17.8 individuals/ha). The total basal area recorded was 17.9 sq m/ha with maximum contribution of 5.4 sq m/ha by *Syzygium cumini*. The other species with high value of IVI were *Trewia nudiflora* (29.4) and *Ficus racemosa* (23.8).

Table 4.11 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Mixed Deciduous Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Mallotus philippensis	73.97	89.08	2.90	79.04
Bombax ceiba	12.33	9.17	3.67	26.31
Syzygium cumini	21.92	12.66	2.07	23.12
Acacia catechu	21.92	11.79	0.63	15.60
Haldinia cordifolia	10.96	4.80	1.75	14.41
Ehretia laevis	13.70	14.41	0.49	13.43
Trewia nudiflora	13.70	9.61	0.76	12.58
Lagerstroemia parviflora	16.44	5.68	0.84	12.03
Aegle marmelos	15.07	10.92	0.43	11.96
Diospyros exscupta	12.33	6.11	0.88	11.11
Tectona grandis	8.22	8.73	0.77	10.48
Terminalia alata	6.85	4.37	0.84	8.36
Drypetes roxburghii	4.11	2.18	0.91	6.83
Lannea coromandelica	6.85	2.18	0.70	6.66
Dalbergia sissoo	6.85	2.62	0.24	4.58
Ficus racemosa	4.11	1.75	0.35	3.86
Schleichera oleosa	4.11	1.31	0.37	3.76
Litsea monopetala	5.48	2.18	0.18	3.66
Grewia tiliafolia	5.48	1.75	0.16	3.35
Eucalyptus citriodora	4.11	2.18	0.15	3.07
Bridelia squamosa	4.11	1.31	0.17	2.76
Shorea robusta	2.74	0.87	0.20	2.28
Streblus asper	4.11	1.31	0.03	2.09
Mitragyna parvifolia	2.74	0.87	0.10	1.79
Cassia fistula	2.74	0.87	0.06	1.59
Bauhinia racemosa	2.74	1.31	0.02	1.58
Ficus hispida	2.74	0.87	0.05	1.51
Butea monosperma	2.74	0.87	0.04	1.46
Buchanania lanzan	2.74	0.87	0.03	1.45
Wendlandia heynei	1.37	0.44	0.11	1.20
Ficus religiosa	1.37	0.44	0.08	1.05
Salix tetrasperma	1.37	0.87	0.03	0.99
Stereospermum chelonoides	1.37	0.44	0.06	0.95
Barringtonia acutangula	1.37	0.44	0.04	0.83

Contd…

Table 4.11 Contd…

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Albizia procera	1.37	0.44	0.03	0.78
Madhuca longifolia	1.37	0.44	0.02	0.76
Litsea glutinosa	1.37	0.44	0.01	0.70
Catunaregam uliginosa	1.37	0.44	0.01	0.69
Ziziphus mauritiana	1.37	0.44	0.01	0.68
Murraya koenigii	1.37	0.44	0.00	0.66

Table 4.12 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Tropical Semi-Evergreen Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Trewia nudiflora	46.88	42.00	3.21	57.41
Syzygium cumini	34.38	33.00	1.61	37.94
Acacia catechu	37.50	25.00	1.55	35.02
Mallotus philippensis	31.25	37.00	1.02	34.62
Bombax ceiba	12.50	11.00	3.05	30.29
Ficus racemosa	18.75	10.00	0.70	15.88
Dalbergia sissoo	6.25	9.00	0.68	10.92
Ficus hispida	9.38	10.00	0.31	9.95
Tectona grandis	9.38	6.00	0.36	8.46
Streblus asper	9.38	8.00	0.16	8.00
Terminalia arjuna	9.38	5.00	0.35	7.92
Drypetes roxburghii	6.25	2.00	0.34	5.43
Schleichera oleosa	6.25	2.00	0.30	5.14
Lagerstroemia parviflora	6.25	3.00	0.21	4.99
Albizia chinensis	6.25	4.00	0.09	4.61
Mitragyna parvifolia	6.25	3.00	0.03	3.72
Haldinia cordifolia	6.25	2.00	0.05	3.41
Ziziphus mauritiana	6.25	2.00	0.03	3.29
Grewia elastica	3.13	1.00	0.16	2.61
Albizia procera	3.13	1.00	0.15	2.55
Aegle marmelos	3.13	1.00	0.13	2.47
Bauhinia racemosa	3.13	2.00	0.03	2.17
Grewia tiliafolia	3.13	1.00	0.01	1.61
Bridelia squamosa	3.13	1.00	0.01	1.59

Table 4.13 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Tropical Seasonal Swamp Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Syzygium cumini	83.33	96.43	5.46	115.50
Trewia nudiflora	33.33	17.86	1.21	29.48
Ficus racemosa .	16.67	7.14	2.41	23.86
Mallotus philippensis	27.78	12.50	0.65	21.29
Acacia catechu	11.11	7.14	1.95	19.08
Albizia procera	5.56	7.14	2.00	17.23
Lannea coromandelica	11.11	5.36	1.48	15.49
Streblus asper	11.11	8.93	0.27	10.70
Shorea robusta	11.11	3.57	0.67	10.02
Bombax ceiba	5.56	1.79	0.63	6.64
Ehretia laevis	5.56	3.57	0.29	5.73
Lagerstroemia parviflora	5.56	1.79	0.41	5.44
Haldinia cordifolia	5.56	1.79	0.24	4.48
Salix tetrasperma	5.56	3.57	0.03	4.31
Bauhinia racemosa	5.56	1.79	0.17	4.10
Mitragyna parvifolia	5.56	1.79	0.04	3.34
Aegle marmelos	5.56	1.79	0.03	3.31

(h) *Terminalia alata* Forest

This vegetation type was represented by 15 tree species with *T. alata* being the dominant one with maximum IVI and basal area of 110.5 and 13.9 sq m/ha, respectively (Table 4.14). *Mallotus philippensis* obtained the maximum value of frequency of occurrence, being 95% followed by *T. alata* (85%). The overall tree density in this type was 279.3 individuals/ha. The maximum density was illustrated by *Mallotus philippensis* with a value of 137.0 individuals/ha followed by *T. alata* (74.1 individuals/ha). The total basal area registered was 24.2 sq m/ha. Two species viz. *Mallotus philippensis* and Sal also contributed significantly to basal area as they obtained values of 3.8 sq m/ha and 2.9 sq m/ha, respectively.

Table 4.14 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in *Terminalia alata* Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Terminalia alata	85.00	74.19	13.90	110.51
Mallotus philippensis	95.00	137.10	3.87	94.78
Shorea robusta	35.00	12.90	2.90	27.53
Mitragyna parvifolia	20.00	16.13	0.78	15.23
Diospyros exscupta	10.00	6.45	0.57	7.79
Tectona grandis	10.00	9.68	0.10	6.99
Lagerstroemia parviflora	10.00	4.84	0.33	6.21
Syzygium cumini	10.00	3.23	0.28	5.42
Albizia chinensis	10.00	3.23	0.26	5.35
Bauhinia racemosa	10.00	3.23	0.11	4.73
Lannea coromandelica	5.00	1.61	0.55	4.41
Schleichera oleosa	5.00	1.61	0.45	3.99
Dillenia pentagyna	5.00	1.61	0.07	2.44
Aegle marmelos	5.00	1.61	0.06	2.40
Ehretia laevis	5.00	1.61	0.02	2.22

(i) Khair and Sissoo Forest

A total of 10 tree species were recorded in this vegetation type. The maximum value of frequency, being 40% was obtained by *Acacia catechu* followed by *Ficus racemosa*. *Trewia nudiflora* and *Dalbergia sissoo* all showed 30% frequency of occurrence (Table 4.15). The overall tree density was 161.2 individuals/ha with maximum value of 38.7 individuals/ha represented by *Acacia catechu* followed by *Trewia nudiflora* (32.2 individuals/ha). The total basal area recorded was 17.9 sq m/ha with maximum depiction of 8.4 sq m/ha by *Ficus racemosa* followed by *Haldinia cordifolia* obtaining value of 3.7 sq m/ha. The IVI values of 10 tree species ranged from 6.8 to 75.2, highest being obtained by *Ficus racemosa*. *Acacia catechu*, *Trewia nudiflora*, and *Dalbergia sissoo* were major co-associates based on IVI.

Table 4.15 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Khair and Sissoo Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Ficus racemosa	30.00	22.58	8.44	75.25
Acacia catechu	40.00	38.71	1.23	49.91
Trewia nudiflora	30.00	32.26	1.12	40.51
Dalbergia sissoo	30.00	22.58	1.52	36.76
Mallotus philippensis	30.00	25.81	0.64	33.82
Haldinia cordifolia	10.00	3.23	3.71	27.40
Bridelia squamosa	10.00	3.23	1.11	12.94
Syzygium cumini	10.00	6.45	0.12	9.42
Catunaregam uliginosa	10.00	3.23	0.06	7.09
Cordia dichotoma	10.00	3.23	0.02	6.89

(j) *Aegle* Forest

This vegetation type was represented by only 6 tree species with *Aegle marmelos* being the dominant one with maximum value of IVI, being 137.3 (Table 4.16 and Plate 4.2). The maximum value of density and frequency of occurrence were also shown by *Aegle marmelos*. The overall tree density and basal area in this type was 175 individuals/ha and 20.2 sq m/ha, respectively. Other important species with high values of IVI were *Diospyros exsculpta* and *Acacia catechu* obtaining values of 72.9 and 48.5, respectively.

(k) Teak Plantation

Teak, an exotic species dominated this vegetation type and shared this type of plantation with 23 other tree species. The overall tree density in this type was 227.8 individuals/ha. The maximum value of density (150.9 individuals/ha), % frequency (93.7%) and basal area (11.4 sq m/ha) were registered by Teak only (Table 4.17). The other species which showed the next highest density and % frequency was *Mallotus philippensis* with values of

36 individuals/ha and 41%, respectively. The overall basal area obtained was 17.5 sq m/ha with contribution of 3.1 sq m/ha by Sal.

(l) Other Plantations

This type comprised of mainly of plantation species viz. *Eucalyptus citriodora, Acacia catechu, Terminalia arjuna, Dalbergia sissoo* (Table 4.18 and Plate 4.3). The maximum frequency of occurrence was represented by *Miliusa velutina* (33.3%) followed by *Ficus racemosa* (22.2). The overall tree density was 201.7 individuals/ha with maximum density being represented by *Miliusa velutina* (60.7 individuals/ha) followed by *Ficus racemosa* (42.8 individuals/ha) *and Terminalia arjuna* (33.9 individuals/ha). The total basal area obtained in this plantation type was 11.4 sq m/ha with maximum value being 3.8 sq m/ha registered by *Eucalyptus citriodora* (3.8 sq m/ha) followed by *Acacia catechu* (2.5 sq m/ha). The maximum value of IVI was obtained by *Miliusa velutina* (51.8), followed by *Eucalyptus citriodora* (48.8).

Table 4.16 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in *Aegle* Forest of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Aegle marmelos	77.78	100.00	3.33	137.36
Diospyros exscupta	66.67	35.71	1.66	72.91
Acacia catechu	33.33	25.00	1.42	48.54
Tectona grandis	22.22	7.14	0.13	15.80
Cordia dichotoma	11.11	3.57	0.49	13.67
Azidrachta indica	11.11	3.57	0.34	11.71

Table 4.17 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Teak Plantation of KAT

Tree species	**Frequency (%)**	**Density (ha^{-1})**	**Basal area (m^2/ha)**	**IVI**
Tectona grandis	93.75	151.00	11.44	174.86
Mallotus philippensis	41.25	36.65	0.72	39.35
Shorea robusta	15.00	7.57	3.15	28.19
Lagerstroemia parviflora	8.75	4.38	0.28	7.58
Terminalia alata	5.00	3.59	0.41	6.21
Ehretia laevis	7.50	3.59	0.11	5.71
Mitragyna parvifolia	6.25	4.38	0.09	5.36
Dalbergia sissoo	3.75	3.19	0.38	5.31
Syzygium cumini	5.00	1.99	0.09	3.70
Dillenia pentagyna	3.75	1.99	0.18	3.67
Aegle marmelos	3.75	1.59	0.03	2.63
Ficus hispida	3.75	1.20	0.05	2.58
Grewia tiliafolia	2.50	1.20	0.13	2.45
Schleichera oleosa	1.25	0.40	0.28	2.34
Bauhinia racemosa	2.50	0.80	0.03	1.68
Lannea coromandelica	1.25	0.80	0.05	1.23
Eucalyptus citriodora	1.25	0.80	0.03	1.07
Emblica officinalis	1.25	0.40	0.05	1.02
Toona ciliata	1.25	0.40	0.04	0.97
Miliusa velutina	1.25	0.40	0.03	0.93
Acacia catechu	1.25	0.40	0.01	0.80
Bridelia squamosa	1.25	0.40	0.01	0.80
Trewia nudiflora	1.25	0.40	0.01	0.79
Litsea glutinosa	1.25	0.40	0.00	0.78

Table 4.18 - Tree Species with Values of Frequency of Occurrence, Density, Basal Area and IVI in Other Plantations of KAT

Tree species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)	IVI
Miliusa velutina	33.33	60.71	0.04	51.89
Eucalyptus citriodora	11.11	16.07	3.87	48.87
Ficus racemosa	22.22	42.86	0.62	40.91
Terminalia arjuna	11.11	33.93	1.72	38.96
Acacia catechu	5.56	1.79	2.55	26.71
Dalbergia sissoo	11.11	10.71	1.10	22.00
Lagerstroemia parviflora	16.67	19.64	0.10	21.34
Haldinia cordifolia	16.67	5.36	0.01	13.49
Syzygium cumini	5.56	1.79	0.96	12.83
Trewia nudiflora	11.11	5.36	0.13	10.89
Tectona grandis	5.56	1.79	0.20	6.24
Mallotus philippensis	5.56	1.79	0.16	5.85

4.4.3 Population Structure

The population structure of tree species was assessed by dividing all enumerated trees (n=3,074) in KAT into 7 girth classes *viz.* 1: 31-60 cm, II: 61-90, III: 91-120, IV: 121-150, V: 151-180, VI: 181-210, VII: >211. Similar analyses were performed on select three important species, two being native i.e. Sal and *T. alata* and one being Teak, an exotic planted extensively.

Population structure of trees in KAT: The results revealed nearly a normal girth class distribution of tree species in KAT with maximum % individuals in 31-60 cm girth class and minimum in 181-210 cm girth class (Fig. 4.1). The pooled girth distribution showed monotonically decreasing % individuals with increasing tree size girth up to largest GBH class, which showed a peak.

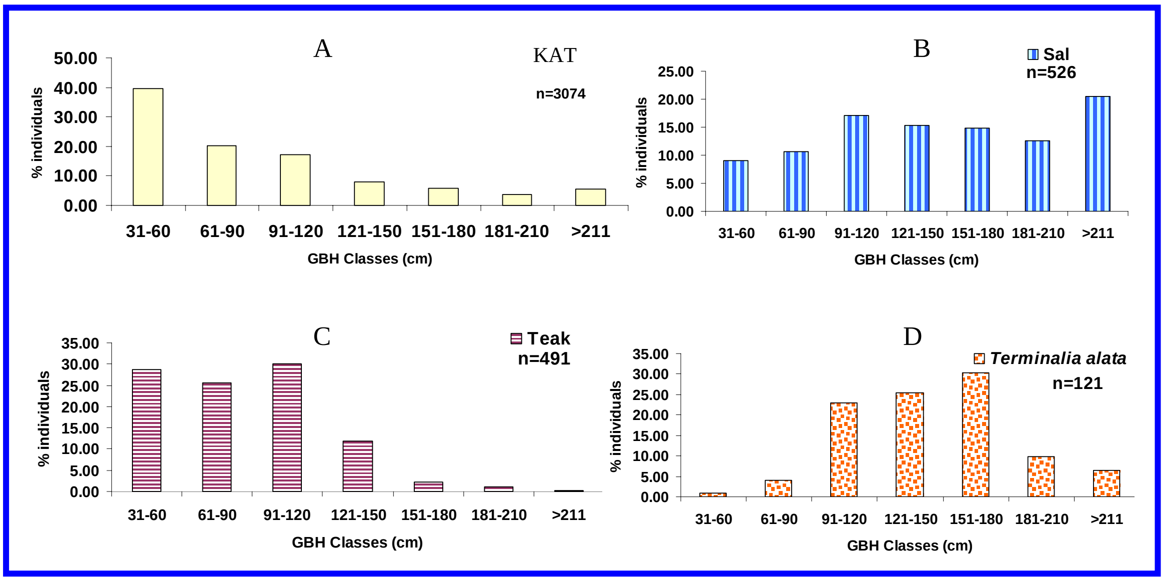


Fig. 4.1 - Girth Class Distribution of Trees in KAT; (A): Includes All Trees in KAT; (B, C, D): Includes Trees of Sal, Teak, and *Terminalia alata* Respectively

Population structure of select trees species: The Sal was present in all the girth classes but was well represented in very large GBH class (>211 cm). Sal was also represented in good proportion in small GBH class (31-60 cm). *Terminalia alata*, being co-associate of Sal forests in top canopy and considering its second highest value of IVI after Sal in top canopy, the assessment on its girth class distribution revealed that the species depicted low proportion of young trees (31-90 cm) and mature trees (>180 cm) whereas maximum representation was of middle aged trees in girth classes (91-180 cm). The poor representation of early classes i.e. establishment and young individuals may be a result of recent management intervention in past 1-2 decades i.e. curtailment of forest working in the area. Occurrence of resultant likely dense canopy might be inhibitive for regeneration and establishment. In contrast, Teak exhibited maximum of young and middle aged trees. Higher girth classes were almost absent or poorly represented.

4.4.4 Diversity Indices

Table 4.19 presents values of Margalef Index (R) for species richness and Shannon's diversity Index (H') for diversity and evenness computed for trees, shrubs, and herbs in KAT. The values of R ranged from 4.6 to 9.1. Trees with highest R value, being 9.1 indicated the greatest species richness among three habits of KAT. The values of H' varied from 1.95 to 2.69. Trees and herbs were relatively more evenly distributed in terms of distribution of species abundance than shrub species.

Table 4.19 - Diversity Indices for Trees, Shrubs, and Herbs in KAT

Diversity Indices ↓	Vegetation Type ►	Trees	Shrubs	Herbs
Margalef Index (R) for Species Richness		9.16	4.98	4.66
Shannon's Diversity Index (H')		2.5	1.95	2.69

4.4.5 Structure and Composition of Grasslands in KAT

The previous Chapter revealed that the two types of grassland (Upland and Lowland) together constitute one sixth of forestland and almost 12% area of in case of KAT as an important, distinct, and integral component of diverse forests (Plate 4.2). The following section specifically describes diversity of trees, shrubs, herbs, and grasses recorded exclusively in 73 vegetation plots laid in both types of grassland.

Tree diversity**:** Trees were seen occasionally amidst grasslands. Only six tree species were recorded in 73 plots sampled in grasslands (Table 4.20). *Bombax ceiba*, *Dalbergia sissoo*, and *Acacia catechu* were three prominent tree species in grasslands based on their values of frequency of occurrence. *Holarrhena pubescens* was the species out of six to be reported from grasslands as five other species were common with forests but it is usually considered as woodland species and in the present study was found in plot near forest. The overall tree density recorded for grassland was 17.0 individuals/ha with the maximum value of 6.5 individuals/ha obtained by *Bombax ceiba*. The total basal area of all trees occurred in grasslands was 0.06 sq m/ha with maximum share made by *Dalbergia sissoo* followed by *Bombax ceiba*. The values of IVI ranged from 7.6 to 114.2. The highest value of IVI was obtained by *Bombax ceiba*, followed by *Dalbergia sissoo* (87.2).

***Shrub diversity*:** A total of 13 species were recorded in grasslands, all these species were commom with shrubs in woodland (Table 4.20). The total shrub density in grassland was 1141.0 individuals/ha with dominance being shown by *Ziziphus mauritiana* having maximum value of IVI, being 93.6 based on highest values of density (521.4 individuals/ha), and frequency of occurrence (23.2%), followed by *Clerodendrum viscosum*. Interestingly highest abundance value of 40 was obtained by *Glycosmis pentaphylla* followed by *Clerodendrum viscosum* (22.1). Important shrub species of grasslands in order of descending values of IVI were *Ziziphus mauritiana, Clerodendrum viscosum, Glycosmis pentaphylla.*

***Herb diversity*:** The sampling in 73 plots in grasslands revealed the occurrence of 7 herb species, out of which 4 were same as that of woodland, and *Leucas cephalotes, Phumaris rubra,* and *Mimosa pudica* were only three exclusive species recorded in grasslands. The total herb density was 1,3424.6 individuals/ha with maximum density value of 8,219.1 individuals/ha obtained by *Oxalis corniculata* (Table 4.20). The maximum value of frequency of occurrence was obtained by *Leucas cephalotes* (4.1%), followed by *Oxalis corniculata* (2.7%), *Phumaris rubra* (2.7%), and *Solanum surrattense* (2.7%). *Oxalis corniculata* also found as the most abundant species in grasslands. The maximum value of IVI, being 141.9 was also obtained by *Oxalis corniculata*. *Leucas cephalotes*, *Phumaris rubra*, and *Solanum surrattense* were other prominent herbs based on their values of IVI.

Table 4.20 - Tree, Shrub, Herb, and Grass Species with Values of Frequency of Occurrence, Density, Basal Area/Abundance and IVI in Grasslands of KAT

Species	Frequency (%)	Density (ha^{-1})	Basal area (m^2/ha)/ Abundance*	IVI
Trees				
Bombax ceiba	10.9	6.5	0.027	114.2
Dalbergia sissoo	5.4	3.0	0.024	87.2
Acacia catechu	8.2	4.3	0.007	57.7
Tectona grandis	1.3	1.3	0.002	16.9
Lagerstroemia parviflora	1.3	1.3	0.002	16.2
Holarrhena pubescens	1.3	0.4	0.000	7.6
Total		**17.0**	**0.065**	
Shrubs				
Ziziphus maurtiana	23.2	521.4	17.1	93.6
Clerodendrum viscosum	8.2	237.5	22.1	50.8
Glycosmis pentaphylla	2.7	142.8	40.0	48.9
Acacia sinuata	5.4	83.9	11.7	24.8
Ichnocarpus frutescens	5.4	44.6	6.2	16.9
Callicarpa macrophylla	4.1	42.8	8.0	16.2
Murraya koenigii	4.1	21.4	4.0	11.1
Flemingia chappar	2.7	19.6	5.5	10.1
Calotropis procera	4.1	7.1	1.3	7.7
Sesbania bispinosa	2.7	8.9	2.5	6.8
Lantana camara	2.7	5.3	1.5	5.6
Tiliacora acuminata	1.3	3.5	2.0	3.9
Ziziphus oenoplia	1.3	1.7	1.0	2.9
Total		**1141.0**	**123.18**	
Herbs				
Oxalis corniculata	2.7	8219.1	30.0	141.9
Leucas cephalotes	4.1	3424.6	8.3	68.3
Phumaris rubra	2.7	684.9	2.5	27.1
Solanum surattense	2.7	547.9	2.0	25.0
Eclipta prostrata	1.3	273.9	2.0	14.6
Sida rhombifolia	1.3	136.9	1.0	11.4
Mimosa pudica	1.3	136.9	1.0	11.4
Total		**13424.6**	**46.83**	
Grasses				
Imperata cylindrica	75.3	-	-	-
Desmostachya bipinnata	38.3	-	-	-
Vetiveria zizaniodes	32.8	-	-	-
Saccharum bengalense	21.9	-	-	-
Saccharum narenga	16.4	-	-	-
Saccharum spontaneum	12.3	-	-	-
Cymbopogon jwarancusa	8.2	-	-	-
Bothriochloa pertusa	5.4	-	-	-
Cyrtococcum patens	2.7	-	-	-
Phragmites karka	2.7	-	-	-
Cynodon dactylon	1.3	-	-	-
Schlerostachya fusca	1.3	-	-	-

***Abundance was calculated in case of shrubs and herbs**
- Variables were not quantified

***Grass diversity*:** The exclusive sampling in grasslands revealed presence of 12 grass species. Out of 12 species, 10 were common with woodland and the rest two i.e. *Saccharum spontaneum* and *Cymbopogon jwaranacusa* were found exclusively in vegetation plots sampled in grasslands. Genus *Saccharum* with representation of three species viz. *S. bengalense*, *S. narenga*, and *S. spontaneum* was the most prominent (Table 4.20). *S. bengalense* obtained relatively highest value of frequency of occurrence, being 21.9% in comparison to two other species. The maximum value of frequency of occurrence, being 75.3% was shown by *Imperata cylindrica* followed by *Desmostachya bipinnata* (38.3%).

4.5 Discussion

Forests in Dudhwa landscape are unique due to two aspects. Firstly, they depict long stretches of contiguous and diverse forests in almost flat land. Secondly, large patches of interspersed Upland and Lowland grasslands within forests not only provide additional plant diversity but also create a holistic and challenging system for management. Undoubtedly, this unique complex character allows greater plant diversity within forest vegetation. However, natural disturbances, management interventions from time to time (e.g. active forest working for almost 100 years followed by an abrupt passive phase, and use of extensive annual fires for grassland management) coupled with enhanced biotic pressure have definitely influenced these forests, once extensive in the entire tract. Now they are neither pristine or natural nor intact. Nevertheless, forest vegetation assessed in KAT revealed high diversity comparable to several other tropical deciduous forests in the world. The following section on one hand highlights plant diversity in KAT and on other hand compares with similar forests in other constituent areas of Dudhwa landscape and other Sal dominated forests within the country, neighbouring Nepal, or other deciduous forests in the world.

4.5.1 Vegetation Structure and Composition

The overall plant diversity of 142 species representing 56 families and 123 genera in KAT is comparable with other similar constituent areas as depicted in the Table 4.21.

Accordingly, plant diversity in KAT is more or less similar with NKFD and SKFD than DNP and KWS. The reasons for low plant diversity in KAT can be attributed to: (i) the occurrence of area under rivers in KAT was more than 8% than area of rivers in DNP and KWS; (ii) occupation of nearly 10% area of KAT by Government Farm; and (iii) nearly double extent of plantations (ca. from 5% to 10%) in KAT than DNP and KWS. KAT recorded second highest number of shrub species among five compared land management units.

Table 4.21 – Comparison of the Plant Diversity of KAT with Other Constituent Area of Dudhwa Landscape

Areas	Trees	Shrubs	Herbs	Grasses	Plant diversity	Families	Genera	Source
KAT	58	32	30	15	142	56	123	Present study
DNP	86	38	89	25	249	73	192	Kumar *et al*. (2002)
KWS	63	23	63	21	181	69	159	Kumar *et al*. (2002)
NKFD	64	25	42	14	143	60	122	Kumar *et al*. (2002)
SKFD	63	27	31	14	154	65	128	Kumar *et al*. (2002)

KAT showed a comparable overall plant diversity in comparison to Sal forests in the western *Terai* of Nepal as Timilsina *et al.* (2007) indicated altogether 131 species represented by 28 trees, 10 shrubs, 6 climber and 87 herbs. It seems that authors have excluded grasses and plant diversity assessment in intervening grasslands.

(a) Tree richness, density, basal area, and IVI

The plant diversity of KAT is also characterized by an overwhelming occurrence of 58 tree species and out of this, *Mallotus philippensis* was the most frequently found species. The Sal, a characteristic species of this tract registered the first place due to the highest value of IVI. Teak, an exotic species to the tract was once widely planted throughout the sanctuary and with lapse of time; it had now fully established itself in the area. Table 4.21 amply revealed that tree species richness was lowest in KAT as compared to other four constituent areas or LMUs. However, Timlisina *et al. (*2007) reported a diversity of 28 tree species in Sal forests of western *Terai* of Nepal. It means KAT registered just more than double tree species than the study area in Nepal. Present study computed overall tree density in KAT as 194 individuals/ha whereas Kumar *et al.* (2002) reported tree density of 450 individuals/ha in TCA. Values of tree density in individuals LMU were not available. More than double value of tree density in TCA than KAT is difficult to argue in absence of factual information or any other evidence. However, in comparison Timlisina *et al. (*2007) reported mean tree density value of 220 individuals/ha in Sal forests of western *Terai*, Nepal. Nevertheless, relatively low value of overall tree density in KAT can be attributed to two possible reasons: (a) probable occurrence of young recruitment classes of Sal and other tree species in DNP due to greater protection and discontinuation of forestry operations much earlier (ca. 20-25 years), and (b) extensive Khair and Sissoo forests in NKFD, harbouring extensive young *Syzygium* trees.

Shukla and Pandey (2000) also reported a much higher tree density of 814 individuals/ha in Sal forest, Gorakhpur. Values of tree density reported for Sal forests in Central India by Jha and Singh (1990) were in range of 249-559 individuals/ha and 324-476 individuals/ha, respectively. These values corresponded to dry deciduous forests in Vindhyan Hills and deciduous forests in Mandla district, India respectively.

The mean basal area of trees computed in the present investigation was 19.6 sq m/ha against 37.4 sq m/ha reported in TCA by Kumar *et al.* (2002).

Shankar (2001) compared vegetation characteristics of Sal forests and other deciduous forests in India and accordingly values of basal area ranged from 7.0 sq m/ha to 56.2 sq m/ha in Sal and other forests wherein individuals with ≥30 GBH were included in assessment. Timlisina *et al. (*2007) reported mean basal area of 13.2 sq m/ha for Sal forests in western *Terai*, Nepal. Hence, values of basal area in KAT are comparable with different forests assessed by other authors.

The values of IVI in case of Sal obtained in the present investigation, being 72.1 was analogous with IVI of Sal in TCA i.e. 79.1 (Kumar *et al.*, 2002). Shankar (2001) reported value of IVI of Sal as 16.2 in Sal dominated lowland forest of Eastern Himalaya. Singh and Singh (1992) reported values of IVI of Sal in Sal old growth forest at three different elevations (300 m, 600-800 m, and 900-1200 m) in Bhabhar and Siwalik regions and accordingly values ranged from 108.4 to 193.1. Shannon diversity of 2.5 at the present site is almost similar to reported for DNP (2.4) and KWS (2.3) by Kumar *et al.* (2002).

(b) Shrub, herb, and grass diversity

The overall shrub density (7345 individuals/ha) in the present study found out to be low as compared to reported in DNP (21531.8 individuals/ha) and KWS (13968.9 individuals/ha) by Kumar *et al.* (2002) but the shrub diversity as expressed by Shannon's diversity index was 1.9 and stood very close to that of DNP (1.8) and KWS (1.6). On the contrary, H' reported by Timilsina *et al*. (2007) for Sal forest in western *Terai* of Nepal was very low (0.1).

Analogously, the overall herb density (65,340 individuals/ha) was also found to be low as compared to DNP (177901.0 individuals/ha) and KWS (134571.3 individuals/ha) but H’ of 2.6 in the present case exceeded value reported by Kumar *et al.* (2002) as 2.2 and 1.9 for DNP and KWS, respectively.

Present study recorded fifteen species of grasses in both woodland and grassland. *Cyrtococcum patens* and *Imperata cylindrica* both found to be most widely distributed. The former was in the case of woodland whereas the later species was more specific to grassland. *Apluda mutica, Paspalum distichum*, and *Eulaliopsis binata* were found only in plots of woodland whereas *Saccharum spontaneum* and *Cymbopogon jwaranacusa* were recorded only in grassland. In comparison to other studies, Timilsina *et al.* (2007) found 20 species of grasses in western *Terai* of Nepal whereas Kumar *et al.* (2002) reported about 25 species from DNP and 21 from KWS.

Nearly 66% tree species (38) in KAT showed few individuals or highly patchy distribution. They obtained values of frequency of occurrence >2% i.e. species occurred in less than 10 plots out of 505 sampled plots. Because of their low or restricted occurrence such species are highly threatened and it is difficult to comment upon their regeneration status. The representation of vegetation communities by a small number of abundance or low frequency species has been highlighted by Gastron (1994), Lehmkuhl (1989), Peet *et al.* (1999), and Kumar et al. (2002).

4.5.2 Management Intervention, Regeneration Status, and Conservation Implications

Long history of active past management that focussed on production forestry and specifically social and economic uses of diverse forests and grasslands in the tract has definitely set forest and grassland ecosystems in the landscape as well as KAT on trajectory of change. Prominent reflections were: (a) demarcation of smallest management unit i.e. compartment and development of rail and forest road network in the tract, (b) heavy forest working, (c) clearfelling of native forests; introduction of exotic (Teak and *Eucalyptus*), adoption of selection system, ignorance of miscellaneous species and loss of old growth forests, and (d) plantation in grassy blanks. These management interventions were enough to alter the structure and composition of forests and grasslands within landscape and having its own implications for native flora and fauna.

Before implications of above active management could be quantified and ascertained, forests and grasslands in KAT and Dudhwa landscape gradually witnessed conservative working and at one time abrupt discontinuance or greatly reduction of all such activities. The forests are today simply protected from forest fires and livestock grazing while majority grasslands are burned annually as ‘prescribed burning’. Passive forest management has now resulted mainly into the wide spread presence of exotics - Teak and *Eucalyptus* and gregarious growth of *Tiliacora acuminata* in Sal forests as an undesirable woody climber. Teak has shown good regeneration and establishment while at the same time *T. alata*, a major co-associate of Sal in top canopy indicated poor regeneration and establishment. This is a cause of worry. Regeneration status of other native tree species is required to be ascertained on a priority. *T.acuminata* has prohibited growth of any other plant in undergrowth causing deficiency of forage to wild herbivores. Kumar *et al.* (2002) have illustrated that there is a direct relationship between closed canopy of Sal and preponderance of *T.acuminata*.

In summary, the present study revealed that KAT was more comparable to NKFD and SKFD as compared to other PAs i.e. DNP and KWS. This indicate still visible impact of past forest working. DNP and KWS appear to have relatively recovered after receiving higher level of protection and suspension of forestry operations. Species diversity is otherwise associated with management interventions in the areas.

Chapter 5

The Landscape – Forest Fragmentation

5.1 Introduction

Contemporary land-use practices in Asia have caused the rapid loss and fragmentation of the region's forests (Whitmore, 1997; Lynam and Billick, 1999). Forest fragmentation is the nearly inevitable result of land use (Corry and Nassauer, 2002). Deforestation has been identified as one of the most pervasive and deleterious processes occurring not only in Asia but in the entire tropics today leading to forest fragmentation and edge effects (Gascon *et al*., 2000; Pattanavibool and Dearden, 2002; Broadbent *et al*., 2008). Forest fragmentation results from the simultaneous reduction of forest area, increase in forest edge, and sub-division of large forest areas into smaller non-contiguous fragments (Laurance, 2000). The fragmentation of a previously continuous habitat entails habitat loss and an increase in isolation, which in turn usually trigger a cascade of biological effects such as edge effects, decreased colonization, increased mortality, and habitat degradation causing an increase in extinction rate, loss of biological diversity and non random patterns of species distribution across fragments (Wilcox and Murphy, 1985; Saunders *et al*., 1991; Soule *et al*., 1992; Cornelius *et al*., 2000).

The terms "forest fragmentation," "habitat fragmentation," and "landscape fragmentation" have been widely used in recent literature in the context of forestry, wildlife management, and landscape ecology. Fahrig (2003) recently carried out a search of the Cambridge Scientific Abstracts database and observed over 1600 articles containing the phrase "habitat fragmentation" and reviewed them for understanding the effects of habitat fragmentation on biodiversity. He realized the task of reviewing of literature daunting not only because of its size but also due to use of different definitions of habitat fragmentation by different authors and also these authors measured fragmentation in different ways and at different spatial scales. Fahrig (2003) based on his review recognized that authors have highlighted "*Fragmentation* *as a Process and as well as Pattern*." Accordingly, habitat fragmentation is often defined as 'a process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original' (Wilcove *et al*., 1986). Quantifying the degree of fragmentation requires measuring the pattern of habitat on the landscape. The definition of habitat fragmentation implies four effects of the process of fragmentation on habitat pattern: (a) reduction in habitat amount or habitat loss, (b) increase in number of habitat patches, (c) decrease in size of habitat patches, and (d) increase in isolation of patches. These four effects form the basis of most quantitative measures of habitat fragmentation. However, fragmentation measures varied widely, some included one effect (e.g. reduced habitat amount or reduced patch sizes), whereas others included two or three effects but not all four. Fahrig (2003) felt that the fragmentation literature can be distilled into two major effects: the generally strong negative effect of habitat loss on biodiversity, and the much weaker, positive or negative effect of fragmentation per se on biodiversity. Because the effect of fragmentation per se is weaker than the effect of habitat loss, it is necessary to experimentally or statistically control the effect of habitat loss so as to detect the effect of fragmentation per se.

Finally, Fahrig (2003) concluded that the term "fragmentation" should be limited to the breaking apart of habitat. '*Habitat loss should be called habitat loss; it has important effects on biodiversity that are independent of any effects of habitat fragmentation per se. Habitat fragmentation should be reserved for change in habitat configuration that result from the breaking apart of habitat, independent of habitat loss*'.

Following sections briefly highlights effects of fragmentation on biodiversity, population dynamics in fragmented landscape and approaches to quantify fragmentation.

5.1.1 Effects of Fragmentation on Biodiversity

Fragmentation isolates and reduces size of habitat patches, increasing vulnerability of local population of plants and animal species to environmental and demographic threats (Lovejoy *et al*., 1986; Wilcove *et al*., 1986). The broader habitat loss increases the distance between habitat patches and the hostility of inter-patch habitat for certain species. In metapopulation, it leads to reduction in the migration rates among habitat patches, causing increase in extinction of local populations and decrease in rates of recolonization of vacant patches (Wilcove *et al*., 1986; Roberts *et al*., 1998; Ishwar, 2001). Other important consequence of forest fragmentation includes increase in the amount of habitat edge. Such areas were considered characterized by increased diversity but mounting evidences now suggest that the abrupt, artificial edges created by fragmentation negatively affect many forest interior species and also ecological processes (Reed *et al*., 1996; Laurance, 2000; Ishwar, 2001). Edge effects include microclimatic changes such as increased desiccation and temperature variability near forest edges which in turn affect many plants and animals. Greater wind turbulence near edges leads to elevated rates of wind-throw and forest structural damage. Predation on bird nests often increased near edges because of influx of generalist predators and brood parasites from surrounding modified habitats. Ecological processes, such as pollination, seed dispersal, nutrient cycling, and carbon storage can also be altered by edge effects. Most empirical studies have found that edge effects penetrate less than 150 m into fragmented forests (Laurance, 2000). The combined repercussion of the above factors leads to population reduction in susceptible forest interior species that require a habitat, at a minimum distance from habitat edge (Roberts *et al*., 1998). Other impacts include increase in tree mortality and penetration of exotic species displacing rare, and endemic native species.

Reed *et al.* (1996) linked fragmentation with decreasing viability and changes in genetic structure of certain populations. The study exemplified that reduced connectivity among populations due to isolation of habitat patches as a result of fragmentation can lead to increased levels of inbreeding, increased differentiation among sub-populations and reduced effective sizes in metapopulations. The loss of genetic diversity due to increased influence of genetic drift reduce the ability of a population to adapt to environmental changes, and inbreeding in local populations lead to reduced individual viability and fecundity. Taken together, environmental, demographic, and genetic effects of habitat fragmentation can accelerate the decline and extinction of species (Couvet, 2002).

5.1.2 Population Dynamics in Fragmented Landscape

The process of landscape change as a result of habitat fragmentation has far-reaching consequences for species survival. Nikolakaki (2004) noted that sufficient empirical evidences are present which suggest that the population dynamics for a wide range of organisms living in fragmented landscapes, particularly for small mammals, invertebrates and birds, follow a pattern of stochastic local extinction and recolonization, and thus occurring as metapopulations.

With respect to impact of fragmentation on avian population, it is acknowledged from the literature that the assemblages of forest birds in fragmented forest are affected by size, shape, and degree of connectivity (or isolation) of forest fragments. The occurrence of most forest birds is dependent upon a minimal area of critical habitat available in order to satisfy foraging needs and territory size requirements. It has been suggested that lack of resources and increased level of predation in small patches may cause high mortality of forest specialists, whereas poor breeding success due to inbreeding and lack of connectivity would further result in high extinction rates (Nikolakaki, 2004).

Many studies have found a positive correlation between forest area and number of species (Martinez-Morales, 2005; Castelletta *et al*., 2005). Martinez-Morales (2005) attempted to assess which characteristics of forest fragment (size, shape, edge, connectivity, extent of forest outside the fragment) influence most the structure and composition of the bird community in a fragmented cloud forest of eastern Mexico. Study observed that the fragment shape to be important but forest size to be most important characteristic for the forest dependent species and found it to be positively related to species richness in the bird community. In contrast, forest border species responded negatively to fragment size but responded positively to the fragment shape. Although, a differential response of forest dependent and border dependent species was found, both responded positively to the extent of their suitable habitat. Similarly, while studying the effect of extreme fragmentation on bird community of Singapore Island, Castelletta *et al.* (2005) also found forest patch area as the major variable determining the number of all bird species.

Cornelius *et al.* (2000) analysed the structure and composition of a bird assemblage in a fragmented relict temperate forest located in Fray Jorge National Park, Northcentral Chile. The relict character and long term isolation of Fray forest gave an opportunity to infer the potential long-term consequences of fragmentation and isolation on bird species assemblages. They also found a positive correlation between number of species and fragment area. In contrast, above studies indicated that the interpatch distance/connectivity is less significant indicator of bird species richness (Castelletta *et al*., 2005; Martinez-Morales, 2005) but decline in species richness after isolation have been recorded.

The studies on the effect of fragmentation on amphibian and reptile species also endorsed the above statement but pointed toward other aspects. Ishwar (2001) quantified the effects of forest fragmentation on the reptilian species in wet evergreen forest of Southern Western Ghats, India and concluded that in the fragmented forests of Anamalais, species richness decline with decreasing fragment size but pointed that persistence of species in a fragmented habitat is related more to habitat quality within and surrounding the fragments and presence/absence of specific microhabitats than to the actual area of the fragments, whose influence seems to have been over-emphasized. In the same area, Vasudevan (2000) has also studied the effect of fragmentation on amphibian species and came up with similar results. Not only this, but alerted that fragmentation has caused the decline in number of amphibian species especially rare ones and predicted that members of genera *Micrixalus, Indirana, and Nyctibatrachus* are likely to go extinct first from the fragment of Anamalais, if the size of the fragment further decreased.

Majority of the work that address the effect of fragmentation have focused on effects on communities and populations (Cushman, 2006; Hinam and St. Clair, 2008). However, within a population, how habitat fragmentation affects reproductive success and the behaviour of individuals that consequently influence population response, very little is known. In one such recent work, Hinam and St. Clair (2008) studied the effect of habitat amount and configuration on the foraging behaviour, provisioning rates and physiological condition of breeding male northern saw-whet owls (*Aegolius acadius*) nested in the fragmented aspen parkland of central Alberta, Canada. Their result suggested that high level of habitat loss and fragmentation reduce the foraging efficiency of male saw-whet owls, increase their levels of physiological stress, and reduce their reproductive success which ultimately decreases population sizes of saw -whet owls.

5.1.3 Measuring Forest Fragmentation

As already stated, forest fragmentation is independent of habitat loss and fragmentation specifically denotes changes in habitat configuration or pattern. Habitat loss account for loss in term of size of the habitat patches whereas configuration or pattern alludes to distribution, and spatial character of patch within the landscape. Some aspects, such as isolation or contagion, nearest neighbour, and interspersion measure the placement and relationship within and in between patches of habitat types. Other aspects such as, shape and core area measure the spatial character of habitat. Thus, these aspects are used as variables to assess fragmentation in any forest (McGarigal and Marks, 1994).

Scientists have been using metrics for quantification of above variables for assessing fragmentation (Reed *et al*., 1996; Lele *et al*., 2008). Use of metrics allows variables to be easily computed over large areas and calculation is less demanding in terms of time and money than collecting detailed data on ground (Schindler *et al*., 2008). Many metrics are available to quantify patch size distribution, patch shape complexity, core area, dispersion, contagion, interspersion, and connectivity (McGarigal and Marks, 1994; Vos *et al*., 2001). Reed *et al.* (1996) used twelve indices to characterize trends in landscape fragmentation due to logging during 1950-1993 in Medicine Bow National Forest, Wyoming, USA. Mladenoff *et al.* (1993) used spatial indices to distinguish between managed and natural landscape in northwestern Wisconsin, USA. Tinker *et al.* (1998) used metrics to analyse the effects of clearcutting and road building on the cover types on the Bighorn National Forest, north-central Wyoming. Lu *et al.* (2002) studied the landscape evolution in the middle Heihe River Basin of north-west China by investigating the changes in various landscape metrics during a decade. Lele *et al.* (2008) assessed forest fragmentation in north-eastern regions of India using landscape metrics.

5.1.4 Dudhwa Landscape

Dudhwa landscape is an intricate combination of natural and human managed patches that vary in size, shape, and arrangement and is the result of complex interactions between natural environment, various organisms, and human activities. The driving natural forces attributable for this complex include the high water table and annual flooding. Besides these natural forces, predominant human induced management intervention in terms of prescribed annual fire in grasslands creates a mosaic of diverse patches. With continuous socio-economic development and increase in population density, human activities have become the much more active force promoting the landscape changes during the past 8-10 decades. Various natural and human induced factors have greatly reduced once extensive natural forests into three relatively larger fragments now serving as three different protected areas (DNP, KWS, and KAT) in a vast pool of agriculture dominated matrix.

The systematic forest working of forests in Dudhwa landscape commenced in 1886 and led to establishment of a road and railway network (Plate 2.3). De (2001) documented that metalled road network traverse 85 km and 10 km in DNP, and KWS respectively. In addition, there are several forest roads which connect all important places in the reserve. These roads are used for monitoring and patrolling and also during the fire season, they serve as effective fire breaks. Forest roads traverse a total of 897 km stretch of DNP and KWS. Together with such a vast and well maintained network of both metalled and forest roads, there is railway track passing through the heart of DNP and cross through both the sanctuaries. The track also traverses a considerable length of 34 km and 11 km within the national park and KWS, respectively. Reed *et al.* (1996) quantified fragmentation due to roads in the Medicine Bow National Forest in south-eastern Wyoming and found that roads added to forest fragmentation more than clearcuts by dissecting large patches into smaller pieces and that road edges may persist longer than natural patch edges or those created by clearcuts. Similarly, Tinker *et al.* (1998) compared the effects of clearcutting and road building on the landscape pattern of the Bighorn National Forest, in north-central Wyoming. At both the landscape and cover class scales, clearcutting and road building resulted in increased fragmentation. Patch core area and mean patch size decreased, and edge density and patch density increased as a result of clearcuts and roads. Clearcuts and roads simplified patch shapes at the landscape scale, but increased the complexity of lodge pole pine patches.

Since most area of Dudhwa landscape had been under the influence of anthropogenic pressure through various developmental activities (road and railway), forest management, changing land use pattern in peripheral areas, trans-boundry biotic pressure from Nepal during the past 8 to 10 decades, an adequate quantitative understanding of how landscape had been transformed by such activities and how it will affect landscape in the future is vital to develop appropriate management policies. The first time, a study on landscape structure analysis was undertaken in this area by Kumar *et al.* (2002). They assessed the spatial structure of DNP, KWS, and two adjacent managed forests (NKFD and SKFD) using different metrics. Similar efforts to quantify fragmentation in KAT are lacking. The present study thus attempted to determine the extent of fragmentation of forests in KAT. A comparison was also made between DNP and KAT so as to understand the difference in extent and magnitude of fragmentation in two protected areas. This gave an idea about the conservation importance of habitat patches in two areas. A comparative study with KWS was not possible due to difference in methodology for the preparation of land use maps for KWS.

5.2 The Objectives

The present investigation aimed to quantify the extent of forest fragmentation in KAT and compare with DNP so as to understand the extent and magnitude of fragmentation in two protected area.

5.3 Methodology

Dataset**:** The land use/land cover maps prepared for DNP and KAT in the present study were used as input layers to quantify fragmentation. The polygon layers (vector format) developed for preparing land use maps were converted into raster format with a pixel size of 100 m. In the present Chapter, only forest classes, nine in case of DNP and twelve in KAT were interpreted for explaining fragmentation.

Computation of metrics**:** As already stated, the degree of fragmentation may be described as a function of the varying size, shape, spatial distribution, and density of patches (Jorge and Garcia, 1997). McGarigal and Marks (1994) have provided software known as FRAGSTATS which is a spatial pattern analysis programme for quantifying landscape structure. FRAGSTATS compute several simple metrics. FRAGSTATS has been widely used in landscape ecology. McGarigal and Marks (1994) described metrics at three levels viz. landscape, class, and patch level and suggested that class indices can be used as indices for fragmentation as these separately quantify the amount and distribution of each class or forest type and thus measure the fragmentation of particular forest type.

Keeping this in view, seven metrics at class level were selected which included all the above variables to assess fragmentation (Table 5.1). The raster version of FRAGSTATS spatial pattern analysis software (ver.3.3) developed by McGarigal *et al.* (2002) was used to calculate metrics by adopting eight-neighbourhood criteria for the definition of patches. To carry out comparison of metrics between two PAs, those metrics which were standardized per unit area were chosen as adopted by Tinker *et al*. (1998). In addition, to assess mean core area, 100 m edge influence was selected (Kumar *et al*., 2002; Laurance, 2000). These indices were also found to be useful in several other landscape level and comparative studies (Hargis *et al.*, 1998; Leitao and Ahern, 2002; Corry and Nassauer, 2005; Miyamoto and Sano, 2008).

Table 5.1 - Metrics Used at Class Level to Quantify Fragmentation in KAT and DNP

Metrics and Abbreviation	Description	Unit
Patch Density (PD)	The number of patches of corresponding forest type divided by total area* (ha) multiplied by 100	patches/ 100 ha
Mean Patch Size (MPS)	The average size of the patches of the corresponding forest type	ha
Edge Density (ED)	Total length of edge involving the corresponding forest type divided by total area (ha)	m/ha
Mean Shape Index (MSI)	The average shape index of patches of corresponding forest type, adjusted by a constant for a square standard (raster)	None
Mean Core Area (MCA)	The average core area of the patches of the corresponding forest type	ha
Mean Nearest-Neighbor Distance (MNN)	The average distance between patches of corresponding forest type, based on edge to edge distance	m
Interspersion and Juxtaposition index (IJI)	The adjacency of each patch with all other forest types	%

* *Total area of respective study site (DNP or KAT)*

5.4 Results

The metrics to quantify forest fragmentation were computed for all twelve and nine forest types in KAT and DNP, respectively as described earlier in Chapter 3. The values of the calculated metrics are presented in Table 5.2

and Table 5.3 for KAT and DNP, respectively. The results are interpreted below one by one, firstly for KAT followed by DNP, and finally a comparison made between two PAs.

5.4.1 Forest Fragmentation in KAT

Patch density and mean patch size**:** The density of the patches as well as mean patch area provides some of the initial elements for the characterization of the magnitude of fragmentation. Patch density is the number of patches of a particular class on a unit area basis. A class with greater density of patches indicate that it is subdivided into many patches and thus could be considered more fragmented. Patch density also serve as good spatial heterogeneity index. A class with greater density of patches points to finer grain; that is high spatial heterogeneity. In case of KAT, the values of patch density ranged from 0.01 patches/100 ha to 0.16 patches/100 ha for 12 different forest classes (Table 5.2). Mixed Deciduous Forest recorded the maximum value of patch density indicating that it is represented by maximum number of patches. The next higher value of patch density was observed in the case of Tropical Semi-Evergreen Forest (0.14 patches/100 ha) followed by Teak Plantation (0.13 patches/100 ha). All different four Sal forest types obtained value of patch density less than 0.05 patches/100 ha.

Another class index based on number of patches is the mean patch size. It denotes average size of the patches of a class. The higher value indicates that the class is represented by patches of large size. In contrast to patch density, mean patch size do a good job of ranking the forest types with respect to fragmentation. As progressive reduction in the size of patches is a key component of forest fragmentation, thus smaller mean patch size indicates more fragmented forest. The values of mean patch size for 12 forests types in KAT ranged from 9.5 ha to 360 ha (Table 5.2). Explicitly, with low patch density, Open Sal Forest obtained highest and significantly large average patch size of 360 ha. The smallest mean patch size was recorded for Other Plantations. Moderately Dense Sal Forest and *Terminalia alata* Forest obtained next highest mean patch size of 168 ha and 121 ha, respectively (Table 5.2). Interestingly, Mixed Deciduous Forest, Tropical Semi-Evergreen Forest, and Teak Plantation with higher values of patch density recorded moderately large average patch size (Table 5.2). On the other hand, Open Sal Forest, Moderately Dense Sal Forest, and *Terminalia alata* Forest with low value of patch density represented large patch sizes. In addition, it was noticed that % area extent covered by Tropical Semi-Evergreen Forest, Mixed Deciduous Forest, and Teak Plantation was maximum (about 10% or high) whereas it was high for Open Sal Forest and Moderately Dense Sal Forest (Table 5.2). Thus, in KAT, Mixed Deciduous Forest, Tropical Semi-Evergreen Forest, and Teak Plantation occurred in large extent and contained several, moderately large patches where as Open Sal Forest, Dense Sal Forest, and *Terminalia alata* Forest covered reasonable amount of area, and contained few but larger patches. In terms of fragmentation, Open Sal Forest, Dense Sal Forest, and *Terminalia alata* Forest were found to be least fragmented.

***Edge density, mean shape index, and mean core area*:** Total edge of a class is the most critical piece of information in the study of fragmentation, most of the adverse effects of fragmentation on an organism, often is directly or indirectly related to edge effects. Edge density measures the total edge length of a class per unit area. In the present study, the edge was calculated as a function of habitat perimeter; hence edge density trends matched with % area extent order i.e. the forest with largest amount of perimeter reported largest edge density. The values of edge density in KAT ranged from 0.6 m/ha to 12.1 m/ha. The highest edge density was recorded for Tropical Semi-Evergreen Forest followed by Mixed Deciduous Forest (10 m/ha), and Teak Plantation (7.5 m/ha) and the lowest was reported for Khair and Sissoo Forest. Interestingly, Open Sal Forest and Moderately Dense Sal Forest those reported low patch density, obtained moderately high values of edge density, being 5.4 m/ha and 4.1 m/ha, respectively. Other Sal forest types obtained lower value of edge density i.e. 2.8 m/ha (Dense Sal Forest) and 1.8 m/ha (Sal Mixed Forest).

Table 5.2 - Fragmentation Measurement Metrics Computed for KAT

Forest Types	% area*	PD (patches /100ha) [a]	MPS (ha)	ED (m/ha)	MSI	MCA (ha)	MNN (m)	IJI (%)
Dense Sal	3.1	0.05	59.9	2.8	1.8	24.2	365.8	56.8
Moderately Dense Sal	5.0	0.03	168.3	4.1	2.0	81.1	628.1	52.6
Sal Mixed	1.9	0.04	54.5	1.8	1.7	23.9	556.7	61.5
Open Sal	7.9	0.02	359.5	5.4	2.3	196.6	215.4	68.8
Mixed Deciduous	11.4	0.16	80.0	10.0	1.7	40.8	567.7	85.9
Tropical Semi-Evergreen	12.4	0.14	98.5	12.1	1.8	45.5	262.3	69.0
Tropical Seasonal Swamp	1.6	0.12	15.2	2.4	1.3	4.8	743.6	74.4
Khair and Sissoo	0.7	0.01	75.0	0.6	1.7	35.7	3876.9	65.6
Aegle	0.7	0.05	16.7	1.2	1.4	3.3	239.3	36.0
Terminalia alata	3.3	0.03	120.7	2.9	2.0	59.0	307.9	39.8
Teak Plantation	9.5	0.13	76.9	7.5	1.7	40.6	323.1	79.9
Other Plantations	1.0	0.10	9.5	1.2	1.2	3.4	671.6	72.1

[a] *Total area used for computation for metrics is area of KAT (40009 ha)*
** Values taken from Table 3.5*

Together with patch size and edge characteristics, another important variable which reveal the impact of fragmentation is complexity of patch shapes as reflected by mean shape index. It measures the complexity of patch shape compared to a standard shape and is based on perimeter-area relationship. In the raster version of FRAGSTATS, patch shape is evaluated with a square standard, shape index is minimum for square patches, and increases as patches become non-square. The results for KAT reflected that mean shape index values for all the forest types was greater than 1 indicating that the average patch shape in all forest types was irregular. The values ranged from 1.2 for Other Plantations to 2.3 for Open Sal Forest (Table 5.2). Thus, patches of Open Sal Forest, *Terminalia alata* Forest, Moderately Dense Sal Forest, Tropical Semi-Evergreen Forest, and Dense Sal Forest were found to be most irregular pointed by their high values of mean shape index i.e. around 2. Patches of Sal Mixed Forest, Mixed Deciduous Forest, Teak Plantation, and Khair and Sissoo Forest recorded mean shape index value of 1.7, hence reported moderate irregularity. *Aegle* Forest, Tropical Seasonal Swamp Forest, and Other Plantations represented almost regular square shape indicated by their low mean shape index value of nearly 1.

Closely related with the increase in the amount of edge is loss of core area. Core area is defined as the area within a patch beyond some specified edge distance. Core area has been found to be better predictor of habitat quality than patch area especially for forest interior species. Unlike patch area, core area is affected by patch shape. Thus, while a patch may be large enough to support a given species, it still may not contain enough suitable core area to support the species. In this study, depth of the edge influence was assumed to be 100 m, so that core area is any area within the patch that is greater than 100 m from an edge. The examination of mean core area values for KAT evinced that it followed the similar trend as mean patch size (Table 5.2). The highest value being 197 ha was recorded in case of Open Sal Forest followed by Moderately Dense Sal Forest (81 ha) and *Terminalia alata* Forest (59 ha). All other forest types obtained values of mean core area less than 50 ha. The lowest value of 3 ha was obtained in case of *Aegle* Forest (Table 5.2). Regrettably, all forest types recorded mean core area less than 50% of mean patch size. As core area is affected by shape, this clearly indicated that differences were mainly due to forest configuration or edge effect rather than due to loss. Thus, mean core area helped in defining the main process of fragmentation in KAT.

***Mean nearest neighbour, and interspersion and juxtaposition index*:** Nearest-neighbor distance is defined as the distance from a patch to the nearest neighboring patch of the same type, based on edge-to-edge distance. Interpatch distance can influence a number of important ecological processes such as population dynamics and species interactions in spatially subdivided populations. In case of KAT, the average distance of similar patch type for Khair and Sissoo Forest was reported to be significantly high, being 3877 m (Table 5.2). For other forest types, values came out to be relatively much lower. The next higher value was obtained by Tropical Seasonal Swamp Forest, being 744 m followed by Mixed Deciduous Forest (568 m) and *Terminalia alata* Forest (308 m). For Tropical Semi-Evergreen Forest and *Aegle* Forest, values came out to be almost similar, less than 300 m. The minimum value of 215 m was reported by Open Sal Forest (Table 5.2).

Interspersion and Juxtaposition Index is based on "patch" adjacencies. Each patch is evaluated for adjacency with all other patch type. The index measures the extent to which patch types are interspersed; higher values result from landscapes in which patch types are well interspersed (i.e. equally adjacent to each other), whereas lower values characterize landscape in which the patch types are poorly interspersed (i.e. disproportionate distribution of patch type adjacencies). The index is not directly affected by the number, size, contiguity, or dispersion of patches. In KAT, the value for Interspersion and Juxtaposition Index ranged from 36% to 86% (Table 5.2). The maximum value was obtained by Mixed Deciduous Forest, followed by Teak Plantation (80%), and Tropical Seasonal Swamp Forest (74%). The lower range was reported by *Terminalia alata* Forest and *Aegle* Forest. The values obtained by all Sal forest types indicated that among all forest types, Sal forests in KAT were moderately interspersed.

5.4.2 Forest Fragmentation in DNP

***Patch density and mean patch size*:** The values of patch density in DNP ranged from 0.01 patches/100 ha for Sal Mixed Forest to 0.21 patches/100 ha for Tropical Seasonal Swamp Forest (Table 5.3). Thus, indicated that Tropical Seasonal Swamp Forest was represented by maximum number of patches and Sal Mixed Forest by minimum number of patches. Mixed Deciduous Forest recorded next higher value of patch density, being 0.14 patches/100 ha. The value of mean patch size ranged from as low as 6.1 ha in case of Other Plantations to as high as 1256.8 ha in case of Moderately Dense Sal Forest. Interestingly, with lower patch density, all Sal forest types registered the higher range of average patch size (Table 5.3). The highest value of 1256.8 ha was recorded by Moderately Dense Sal Forest followed by Dense Sal Forest (974 ha), Open Sal Forest (450 ha), and Sal Mixed Forest (361 ha). All other forest types obtained average patch size less than 100 ha except in case of Teak Plantation (115 ha).

Table 5.3 - Fragmentation Measurement Metrics Computed for DNP

Forest Types	% area*	PD (patches/ 100ha)[a]	MPS (ha)	ED (m/ha)	MSI	MCA (ha)	MNN (m)	IJI (%)
Dense Sal	11.4	0.01	974.2	3.3	2.3	781.0	2181.8	70.5
Moderately Dense Sal	23.5	0.01	1256.8	8.0	2.3	965.3	424.9	80.6
Sal Mixed	3.7	0.01	361.1	1.5	1.8	259.1	1492.9	70.9
Open Sal	17.7	0.02	449.5	5.8	2.4	307.6	978.1	75.8
Mixed Deciduous	8.3	0.14	59.9	7.0	1.5	29.5	596.2	79.8
Tropical Semi-Evergreen Forest	2.1	0.02	95.7	2.0	2.0	38.1	864.8	58.5
Tropical Seasonal Swamp Forest	3.9	0.21	18.5	5.8	1.5	4.5	326.9	64.4
Teak Plantation	5.0	0.04	114.8	3.3	1.7	65.3	1031.6	78.4
Other Plantations	0.1	0.02	6.1	0.2	1.2	0.1	1106.6	64.2

[a] *Total area used for computation for metrics is area of DNP (68003 ha)*
** Values taken from Table 3.5*

***Edge density, mean shape index, and mean core area*:** The highest edge density of 8 m/ha was recorded by Moderately Dense Sal Forest whereas lowest value of 0.2 m/ha by Open Plantations (Table 5.3). The Moderately Dense Sal Forest was followed by Mixed Deciduous Forest (7 m/ha), Open Sal Forest (5.8 m/ha), and Tropical Seasonal Swamp Forest (5.8 m/ha). Values of mean shape index ranged from 2.42 to 1.27 which indicated that the average patch shape of all the forest types was irregular (Table 5.3). The highest mean shape index values of 2.42, 2.38, and 2.37 were obtained by three Sal forest types i.e. Open Sal Forest, Dense Sal Forest, and Moderately Dense Sal Forest, thus pointing towards their nativeness to the tract. The lowest range was reported by Tropical Seasonal Swamp Forest (1.51) and Other Plantations (1.27). The examination of mean core area values pointed that it followed the similar trend as mean patch size (Table 5.3). Albeit high edge density, Moderately Dense Sal Forest (965 ha) recorded the highest value of mean core area. The lowest value was obtained by Other Plantations (0.13 ha). Almost all forest types recorded mean core area more than 50% of mean patch size. As core area is affected by shape, this clearly indicated that effect of edge is relatively low in forest types of DNP.

***Mean nearest neighbour, and interspersion and juxtaposition index*:** The average distance of similar patch type came out to be highest for Dense Sal Forest (2,182 m) followed by Sal Mixed Forest (1,493 m). This indicated that their patches were most isolated. Other Plantations and Teak Plantation reported moderately high value of mean nearest neighbour. For other forest types, values came out to be less than 1,000 m. The overall interpretation revealed that patches of forest types in DNP were located relatively at far distance from each other (Table 5.3). The minimum value was registered for Tropical Seasonal Swamp Forest, being 327 m which pointed that even though Tropical Seasonal Swamp Forest was represented by maximum number of patches, these patches were present close to each other.

The values for interspersion and juxtaposition index ranged from 58% to 81% (Table 5.3). The high value of index indicated that all forest types were well interspersed in DNP. The maximum interspersion was reported by Moderately Dense Sal Forest followed by Mixed Deciduous Forest (80%), Teak Plantation (78%). The low interspersion was recorded by Other Plantations and Tropical Seasonal Swamp Forest. All Sal forest types obtained value more than 70% indicated that all Sal forest types in DNP were highly interspersed.

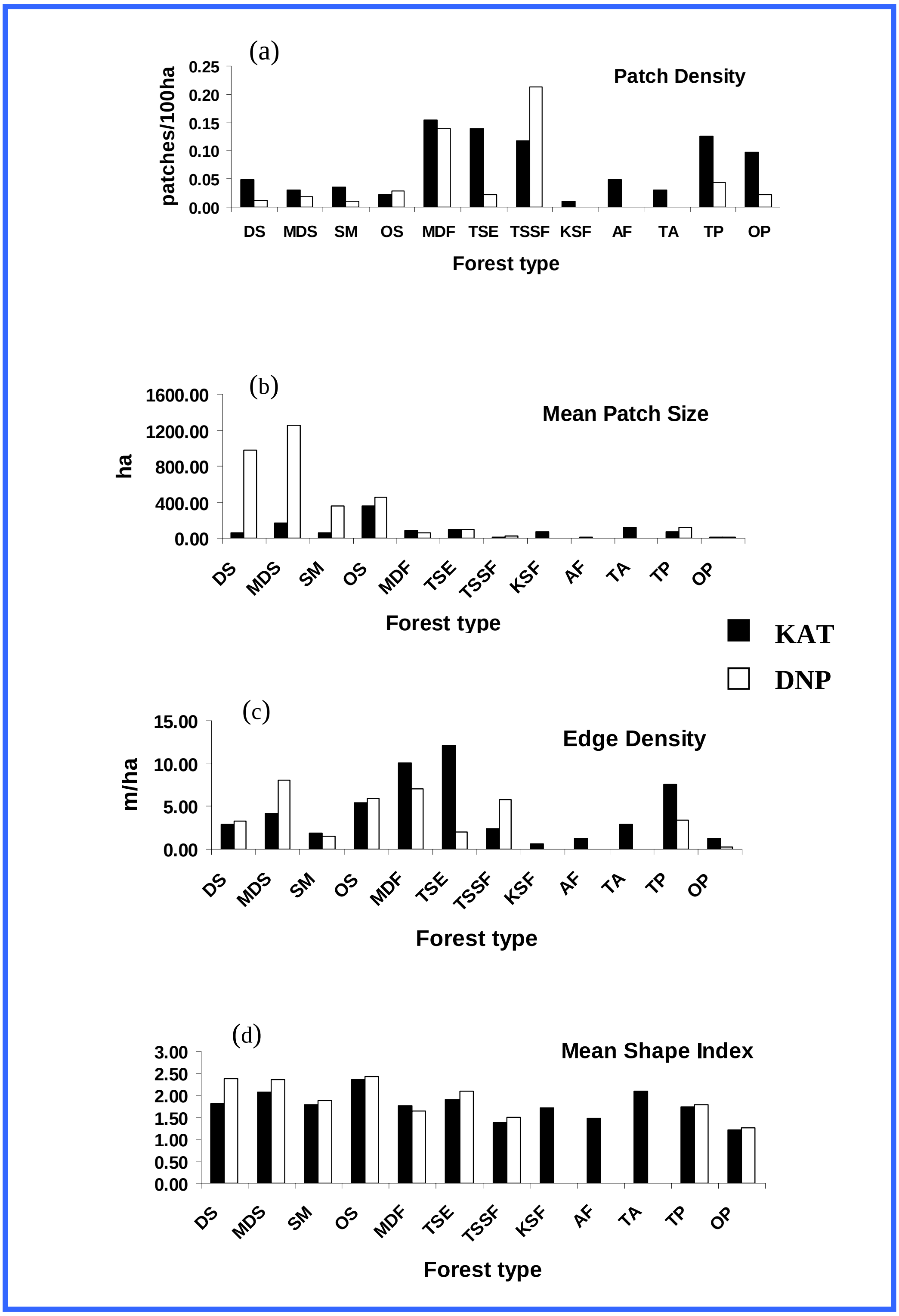
5.4.3 Forest Fragmentation - Comparison of KAT and DNP

A comparison of extent of fragmentation in KAT with DNP based on seven metrics allowed several interesting revelations (Fig. 5.1 and 5.2). They are highlighted below:

Values of patch density in KAT and DNP are compared in Fig. 5.1 (a). Comparison revealed that that most of the forest types in DNP obtained lower values of patch density than KAT indicating that forest types in DNP were relatively less fragmented. As an exception, Tropical Seasonal Swamp Forest in DNP was represented by almost double number of patches as compare to KAT.

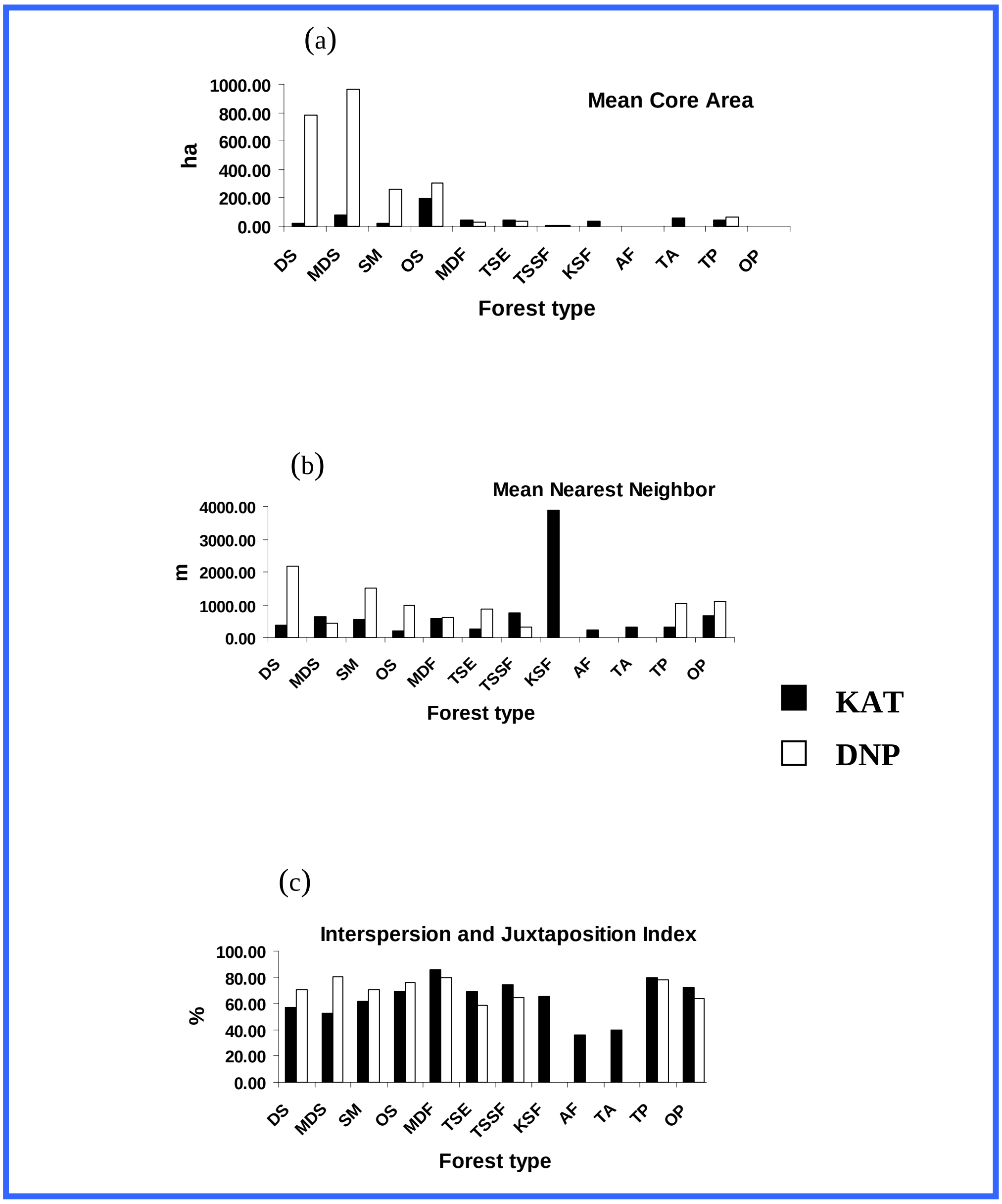
Comparison of values of mean patch size in two PAs showed some striking differences as values of mean patch size in KAT ranged from 9 ha to 360 ha whereas in DNP, it was significantly higher i.e. 6 ha to 1257 ha (Table 5.2 and 5.3; Fig. 5.1b). This revelation pointed that patches of forest types in DNP were larger in sizes, specifically in case of four Sal forest types. In case of other forest types, Mixed Deciduous Forest, Tropical Semi-Evergreen Forest, Teak Plantation, and Other Plantations**,** the value of mean patch size were almost same in two PAs. However, lower value of patch density in such forest types in DNP suggested that these forests were present in less fragmented state in DNP (Fig. 5.1a and 5.1b).

Fig. 5.1c compares values of edge density in two PAs and revealed that Sal forest types in KAT and DNP registered almost same edge density except for Moderately Dense Sal Forest. However, all other forest types recorded higher edge density in KAT except Tropical Seasonal Swamp Forest. The overall comparison indicated that the effect of edge was less prominent in DNP. The comparison of mean shape index in two PAs could not allow any striking differences (Fig. 5.1d). Only, Dense Sal Forest and Moderately Dense Sal Forest accounted for slightly higher value of mean shape index which indicated their irregularity in shape and pointed towards being present in relatively natural state in DNP.



(DS: Dense Sal Forest; MDS: Moderately Dense Sal Forest; SM: Sal Mixed Forest; OS: Open Sal Forest; MDF: Mixed Deciduous Forest; TSE: Tropical Semi-Evergreen Forest; TSSF: Tropical Seasonal Swamp Forest; TA: Terminalia alata Forest; KSF: Khair and Sissoo Forest; AF: Aegle Forest; TP: Teak Plantation; OP: Other Plantations)

Fig. 5.1 - Comparison of Values of Metrics (Patch Density, Mean Patch Size, Edge Density, and Mean Shape Index) for Different Forest Types in DNP and KAT



(DS: Dense Sal Forest; MDS: Moderately Dense Sal Forest; SM: Sal Mixed Forest; OS: Open Sal Forest; MDF: Mixed Deciduous Forest; TSE: Tropical Semi-Evergreen Forest; TSSF: Tropical Seasonal Swamp Forest; TA: Terminalia alata Forest; KSF: Khair and Sissoo Forest; AF: Aegle Forest; TP: Teak Plantation; OP: Other Plantations)

Fig. 5.2 - Comparison of Values of Metrics (Mean Core Area, Mean Nearest Neighbour, Interspersion and Juxtaposition Index) for Different Forest Types in DNP and KAT

Notably, the values of mean core area in case of different forest types in DNP were much higher than in KAT (Fig. 5.2a). Notably, contradictory to general trend of value of mean core area, being 50 % of mean patch size in KAT, value of mean core area came out to be significantly higher in DNP. This could be attributed to less edge effect in DNP as highlighted above. The result indicated towards better habitat quality for forest interior species in DNP as compared to KAT.

The values of mean nearest neighbour for different forest types in KAT ranged from 215 m to 3,876 m whereas in DNP, these values varied from 327 m to 2,182 m (Fig. 5.2b). However, while comparing individuals forests, values were found to be low in KAT for most of the forest types as compared to DNP. This indicated that although forests were less fragmented in DNP but patches were located far apart from each other. Only exception was found in the case of Tropical Seasonal Swamp Forest as it registered low value of mean nearest neighbour in DNP which indicated that its several patches were present close to each other.

The interpretation of values for interspersion and juxtaposition index indicated that most of the forest types in both PAs reported almost same interspersion (Fig. 5.2c). The only exemption was shown by Dense Sal Forest and Moderately Dense Sal Forest which obtained significantly high value in DNP which indicated that both forests were highly interspersed in DNP as compared to KAT.

5.5 Discussion

The dynamic process of forest fragmentation in Dudhwa landscape is amply evident as formerly large contiguous forest expanse has turned into forest patches of varying sizes and they are isolated from each other by tracts of agriculture dominated matrix. Thus, Dudhwa landscape today harbours three large and several small spatially separated forest fragments. This situation is predominantly a result of agriculture expansion in past six decades or so. The only connectivity left among fragments through riparian forests has also diminished in recent past. The present study quantified the magnitude of fragmentation in two large fragments i.e. DNP and KAT. Both these fragments have been subjected to extensive as well as intensive forest management during first 7-8 decades of the twentieth century which primarily included the development of infrastructure (rail and road network, fire lines, and building), clear cutting, selection felling, silviculture operations, and plantations. These activities have led to further fragmentation of forests within the larger fragments. However, these primary activities have almost ceased or drastically curtailed during the last 2-3 decades. But once a few small, scattered hamlets within these large fragments inhabited by tribal or other forest dwelling communities have now grown multifold due to rapid socio-economic development and agriculture expansion. Furthermore, two large fragments investigated in the present study also found effected by severe fragmentation during the past 4-5 decades due to large scale deforestation across international border. Present study provides baseline information on the extent of fragmentation in DNP and KAT using seven metrics described by McGarigal and Marks (1994) and McGarigal *et al*. (2002). Effects of fragmentation on spatial pattern in the present context are discussed below:

5.5.1 Fragmentation and Spatial Pattern

The forces that cause forest fragmentation also result in spatial patterning. Spatial pattern will occur even in the absence of disturbance and succcessional processes. Fragmentation by definition implies creation of patches and reduction in patch size of remaining blocks of habitat. Considering actual area extent of each forest types, patch density, and mean patch size of forest types in KAT and DNP, it can be stated that four Sal forest types in DNP were less fragmented than four Sal forests in KAT. Notably, besides Sal forests being greatly fragmented in KAT, the mean patch size recorded in case of Dense Sal Forest, Moderately Dense Sal Forest, and Sal Mixed Forest was of highly reduced size than similar forest types in DNP. Other forest types *viz.* Mixed Deciduous Forest, Tropical Semi-Evergreen Forest, Teak Plantation, and Other Plantations registered similar values of mean patch size in both PAs but low value of patch density in DNP suggested that these forests were also present in less fragmented state in DNP. The only exception was showed by Tropical Seasonal Swamp Forest. It reported similar values of mean patch size but significantly high value of patch density in DNP which indicated its fragmented state in DNP. Fragmented state of Tropical Seasonal Swamp Forest could be the result of these forests occurring naturally in small patches along rivers and streams.

Results described on edge density indicated that the effect of edge was less prominent in various forest types in case of DNP than KAT. Likewise, values on mean core area revealed that different forest types in DNP recorded significantly higher value of mean core area as compared to trend followed by forest types in KAT, i.e. obtaining less than 50% of mean patch size. This indicated that the forests in DNP harboured better habitat quality than forests in KAT. In addition, this difference in mean core area also gave the cue about the process of fragmentation in KAT which encompass significant impact due to changes in configuration rather than due to forest loss. The values of mean shape index for different forest types in DNP and KAT could not provide any notable difference. Interestingly, along with all forest types, Teak Plantation also registered irregular shapes indicating these forests are now fully established in this tract. The values of mean nearest neighbour for forest types in both PAs provided striking insight. Accordingly, different Sal forest types in DNP otherwise found fragmented as compared to KAT, were represented by patches located far apart from each other. Lesser interconnectivity among patches of similar class could effect movement and dispersal of a faunal species. Lower value of average distance in case of different Sal forest types in KAT points towards the possibility of fragmentation of one large forest patch in recent past resulting into several smaller patches located nearby. Lower value of mean nearest neighbour in case of Tropical Seasonal Swamp Forest in DNP and Tropical Semi-Evergreen Forest in KAT indicated that these two featured forest types were highly localized in respective PA. The value of interspersion and juxtaposition index amply indicated that forest types in both PAs are almost similarly interspersed with just two exceptions of Dense Sal Forest and Moderately Dense Sal Forest which were found to be highly interspersed in DNP.

The high patch density, moderately large patch size, and large extent in KAT of Teak Plantation indicated that it could be a important factor in significant alteration in natural spatial pattern in KAT. The findings support other studies on fragmentation indicating that forest management tends to increase the number of patches, decrease the mean patch size and interior forest habitat (enhanced edge, and mean core area), and decrease the amount of old growth forests (Ripple *et al*., 1991; Spies *et al*., 1994, Staus *et al*., 2002; Bennett, 2003, Holt and Debinski, 2003, Miyamoto and Sano, 2008).

5.5.2 Effects of Fragmentation and Management Implications

Fragmentation is disruption of continuity, but the particular type of continuity that is disrupted is always contextual in a particular situation and need to be specified with respect to organisms, or ecological processes, or preferably both (Haila, 1990; Lord and Norton, 1990; Wiens, 1995). There are hundreds of descriptive studies of fragmentation and a large growing body of relevant theory (Holt and Debinski, 2003). The harmful consequences that follow from fragmentation are amply documented in ecological literature (Haila, 1990; Bennett, 2003). These are usually divided into three main types: (a) effect of the reduction in area of the remaining fragments; (b) effect of increasing isolation of the fragments from each other; and (c) effect of increasing disturbances from the surrounding (Harris, 1984; Wilcove *et al*., 1986; Hunter, 1990; Saunders *et al*., 1991; Haila *et al*., 1993; Noss and Csuti, 1994; Haila, 1994). Curtis (1956) has provided a classical account of the effect of forest fragmentation on forest vegetation. Harris (1984) presented a concise overview of fragmentation and forests. The effects of fragmentation in the context of conservation biology have been reviewed by Hunter (1990); Saunders *et al*. (1991), and Fahrig and Merrian (1994). Effects of fragmentation on wildlife include: loss of species in fragments, changes in the composition of faunal assemblages and changes in ecological processes that involve animals (Bennett, 2003). A range of evidence shows that fragmentation induced isolation of patches, and the degree of spatial isolation, have negative impacts on many populations and communities. The negative effects of isolation are attributed to the decreased opportunity for movement of animals to and from other forest fragments/patches or habitats. Ideas of fragmentation have been heavily indebted to two ecological theories, named island biogeography (MacArthur and Wilson, 1967) and metapopulation dynamics (Levins, 1969; Hanski and Gilpin, 1991). Both these are deductive, formal theories which aim at driving predictions from a set of assumptions. The challenges for managers are to realize the potential significance of forest fragmentation and to identify measures to alleviate harmful effects (Hunter, 1999).

In context of Dudhwa landscape, it can be reiterated that this landscape makes a significant part of globally important 200 ecoregions for its unique large mammal assemblages (Johnsingh *et al*., 2004). The top predator of the area is tiger, an endangered species. Tiger has been recognized as a prominent species in the Indian sub-continent to achieve conservation goals as it has been widely designated as the flagship or an umbrella species. Seven species of wild ungulates viz. nilgai, sambar, swamp deer, chital, hog deer, barking deer, and wild pig are the prey of tiger in the area. Besides these seven wild ungulates, area used to harbour a good population of wild elephant, one horned rhino, and wild buffalo. Later two species were locally extinct much before mid of the twentieth century. A small population of wild elephant occasionally moves in the landscape from adjacent forests/PAs in Nepal. Rhinos were reintroduced in the area in 1980s. Swamp deer, an obligate of tall grasslands has been recognized as the highly endangered species. Hence, forest management has focussed on protection and conservation of this species way back in 1960s. Bengal florican, hispid hare, and swamp frankolin are three important obligate species to interspersed grasslands and swamps. Forest fragmentation has influenced all above mentioned featured as well as other species of conservation concern in one or the other way. Johnsingh *et al*. (2004) and Jhala *et al*. (2008) have recently carried out field assessments on the status of tigers, co-predators, and prey and also on the status of corridors covering parts of Dudhwa landscape. Accordingly, DNP, KWS, KAT, and forests of NKFD, SKFD, and Pilibhit Forest Division constitute a major population of tiger and this is the only major population of tigers in the entire state of Uttar Pradesh. The forested area with tiger occupancy constituted by this population is around 1,900 sq km. This population is connected across the Nepal border *via* the forests of Pilibhit (Lagga-Bagga) to Sukla Phanta of Nepal and KAT is connected across the border of Bardia National Park in Nepal. This major population referred as ‘Dudhwa Tiger Population’ forms three distinct units comprising of KAT, DNP, and KWS-Pilibhit that have intervening land between them under private ownership. Tiger density in three units ranged from 4.5 tigers/100 sq km to 6.5 tigers/100 sq km against the highest density of 19.6 tigers/100 sq km in Corbett Tiger Reserve, Uttarakhand (Jhala *et al*., 2008). Johnsingh *et al.* (2004) concluded that Pilibhit-KWS and DNP in entire *Terai* are currently the best areas for wild ungulates. In KAT, only the northern portion supports relatively undisturbed, rich habitats for wild ungulates, whereas the southern portion is heavily disturbed by train and vehicular traffic and is also under profuse human disturbance. They also highlighted that chital measures significantly closer to tiger indicating that tiger distribution is more closely related to chital than other wild ungulates. Other important wild preys are sambar and pig. The highly endangered swamp deer today occurs in few small pockets (*taal*) within DNP, KWS, and KAT and chances of genetic exchange between these sub-populations have almost diminished. DNP has been recognized as an isolated tiger habitat though this area has tenuous connectivity with KAT to the east and Basantha forests in Nepal to the north; tiger movement between these forests is reported to be only occasional. Within DNP, distribution of tiger was uneven, largely concentrated in the southern and south-eastern part. Dudhwa Tiger Population forms a part of the metapopulation composed of Shukla Phanta and Bardia as the other source populations in Nepal.

Above referred two studies on tigers and prey have amply indicated that the Dudhwa landscape, particularly three large forest fragments/PAs (DNP, KWS, and KAT) combinedly remain important source population but at the same time spatially isolated. Over the years, the connectivity amongst three fragments has almost disappeared. Johnsingh *et al.* (2004) have also revealed that tigers use riparian forests only occasionally as stretches along Sharda River are highly disturbed. Kumar *et al.* (2002) have also stressed that the distinct landscape management units (LMUs) in the area are isolated in the agricultural matrix and connectivity will be very difficult to establish because of private ownership, exorbitant land cost, and the pressures of resource dependency on already depleted riparian forests and other scattered small forest fragments in the landscape.

Despite above stated extent of forest fragmentation and its influence on major species of conservation, the dynamic process of fragmentation with a much higher pace is on within three large fragments due to various biotic and management activities inside as well as outside. The matrix in case of Dudhwa landscape is now under severe influence of all round development. Future conditions in the matrix are pivotal to studies of forest fragmentation, metapopulation dynamics, extinction proneness, edge effects, and conservation efforts in reserves (Lindenmayer and Franklin, 2002). The effect of the matrix on remnant fragments has received the majority of attention in forest fragmentation research (Bustamante *et al*., 2003). The matrix may include several types of drastic abiotic changes in fragments. Dudhwa landscape, therefore calls for assessment of changes in spatial patterns in the matrix on an urgent basis.

In gist, the present study amply illustrated that changes driven by humans had far-reaching consequences in the Dudhwa landscape across time and space. Habitat loss and fragmentation represent the most diverse effects of human on landscape. The expected effect of rapid changes in the matrix would have obviously negative biodiversity and specifically on movement and dispersal of several endangered faunal species.

Chapter 6

The Landscape – River Dynamics

6.1 River Dynamics

Rivers are defined as 'a relatively large volume of water moving within a visible channel, including sub-surface water moving in the same direction and the associated floodplain and riparian vegetation' (Naiman and Bilby, 1998). Rivers are among the most fascinating and complex ecosystems on the earth. Rivers have also been recognized as complex freshwater wetlands that not only include the bed, banks, and water of the watercourse, but also the associated ground waters and the floodplain related wetlands. Rivers, as ecological systems are highly variable over space and time, and exhibit high degree of connectivity between different components of the system whether it is longitudinally, laterally, and vertically (Naiman *et al*., 1992 and 1995).

Rivers perform several natural functions important to living creatures, including people. A river and surrounding land provide wide ranges of habitat for diverse fauna and rivers are also being used by people for various purposes *viz.* fishing, swimming, boating, transportation, etc. touching all parts of the natural environment and nearly all aspects of human culture, rivers along with numerous related streams act as integrators and centres of organization within the landscape.

Throughout its life, a river and the nearby land change. Rivers are dynamic. As they flow, they are constantly cutting, scouring, depositing, and reworking the landscape. It is a process that can seem infinitely slow and its effects are not always apparent-even at the river's edge. But, viewing from the air, the curves and abandoned oxbows, the point bars and islands reveal how rivers modify landscapes. All rivers tend to flow in a sinuous pattern in their natural form, they are in a constant state of change, roaming about across unrestricted floodplain, creating and destroying side channels, backwater, oxbow lakes, and a variety of other habitats. In this process, over long periods, rivers maintain a relative balance between these various habitats, a situation called “dynamic equilibrium” (National Research Council, 1992). Rivers can not in the slightest degree be considered as microcosms – ‘a little world for itself’ (Forbes, 1887; Sioli, 1975). Instead, rivers are through flow systems that receive all water passing through them from the surrounding landscape and conduct it to the ocean or lakes. For their existence, river depends on continuous input as well as continuous output (Sioli, 1975). Both are factors, however, that are not part of the rivers themselves. Thus, when one of these factors stops, rivers cease to exist. They may either dry up or turn into swamps or lakes. In any case, they are rivers no more. Thus, rivers are nothing else than functional parts of higher units of landscapes, of geosynergies (Schmithusen, 1963), or biogeocoenoses (Sukachev, 1964; Sioli, 1975), on whose existence they depend. In fact, the presence of a periodic ‘flood pulse’ is a key factor in maintaining a healthy river ecosystem (Junk *et al*., 1989; Sioli, 1975). Karr (1998) has described rivers as ‘sentinels’ as along with streams they serve as a continent’s circulatory system, and the study of those rivers, like the study of blood, can diagnose the health not only of the rivers themselves but of their landscapes. Changes on the landscape are likely to influence rivers. Land uses such as forest practices, road building, and livestock grazing have important implications for peak flows and floods, water yield and hydrologic recovery (Ziemer and Lisle, 1998). The effects of land uses varies with basin size and the magnitude of flows, and recovery processes, which vary in space and time, depend on the type of disturbance and the hydrologic processes affected. People compromise river flow and health when they divert water, construct dams to harness hydropower or control flooding. They also degrade rivers in several ways. According to Sioli, (1975), rivers in their basic character are products of the water economy of the drainage area. The water economy depends not only on the geographic-geomorphologic situation of the drainage area as external climatic factors but also very strongly on the vegetation cover of the drainage area.

Most of the business of a river is conducted through its channels (Mount, 1995). The day-to-day task of handling discharge, the year-to-year task of eroding, transporting, and depositing sediment, and the long-term adjustments toward some equilibrium are all dependent on processes that occur within or immediately adjacent to a river's main channel.

6.1.1 River Channel – Processes and Pattern

Channels ranging in size from small ephemeral rivulets to large rivers exhibit a wide variety of morphologies, but share a number of basic processes (Montgomery and Buffington, 1998). Channel morphology is influenced by both local and systematic downstream variation in sediment input from upslope sources (sediment supply), the ability of the channel to transmit these loads to downslope reaches (transport capacity), and the effects of vegetation on the channel processes. Potential channel adjustments to altered discharge and sediment load include changes in width, depth, velocity, slope, roughness, and sediment size (Leopold and Maddock, 1953; Montgomery and Buffington, 1998).

'Channel pattern' or 'channel planform' is spatial arrangement of channels in the landscape. It has been grouped into three basic types: Straight, Meandering, and Braiding (Leopold and Wolman, 1957; Schumm and Khan, 1972; Lewin and Brewer, 2001; Takagi *et al*., 2007). Straight rivers follow straight direction of flow. They generally favoured in setting with steep gradients, resistant rocks, and linear features such as joints and fractures. Steep gradients enable water to flow in the straightest path downhill where as resistant rock inhibits sideways (lateral) erosion. Erosion generally takes place downward into the underlying strata. Meandering rivers occupy one relative single-threaded sinuous channel that migrate across the floodplain by erosion of concave bank (cut bank) and deposition on convex bank (point bar) as presented in Fig. 6.1. Braided rivers are characterised by multiple channels that split off around alluvial islands and rejoins each others to give braided appearance (Fig. 6.1). Typically such rivers are highly unstable, with islands consisting of transient sand and gravel bars (Ward, 1998).

Planform develops for a number of reasons, and most planform described above are in continuum. It depends upon the width: depth ratio, bank stability, sediment transport rate, and bed load transport. Sediment transport rate itself is dependent upon stream power. In case of straight rivers, steep gradient and resistant rocks (bank stability) force the river to flow quickly downslope, thus river has enough energy to hold material it is carrying, and hence no deposition occurs.

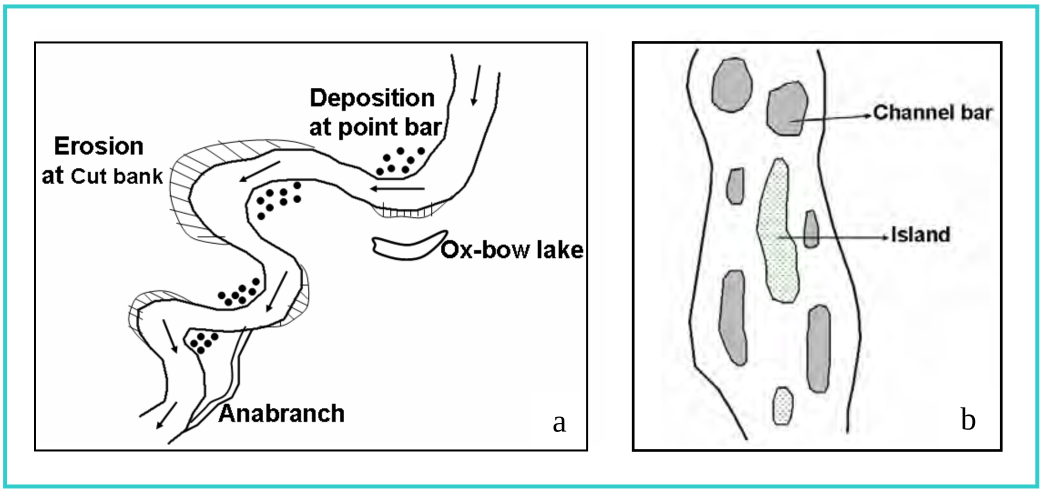


Fig. 6. 1 - Channel Planform Principle Features of (a) Meandering River, and (b) Braiding River

(a) Dynamics of Meandering Rivers

The scarcity of perfectly “straight” channels is widely believed to indicate that meandering is more preferred state. The intensity of meanders or bends in the river reflects the effort of a river to maintain energy efficiency while balancing energy expenditures throughout its length. Meandering occurs whenever local perturbations in erosional resistance of bed or bank materials occur. These differences cause a deviation in the flow path which force the river to develop meanders. Meandering rivers usually occur on gentle gradients wherein bank erodibility is low and load is moderate. The growth of a meander depends on erosion and deposition during the lateral movement of channel across floodplain. The erosion occurs on the convex bends of the river and is called cut bank. The rate of lateral migration of the cutbank is usually matched by deposition on the opposite bank. This deposition forms the prominent sedimentary feature called point bar (Fig. 6.1).

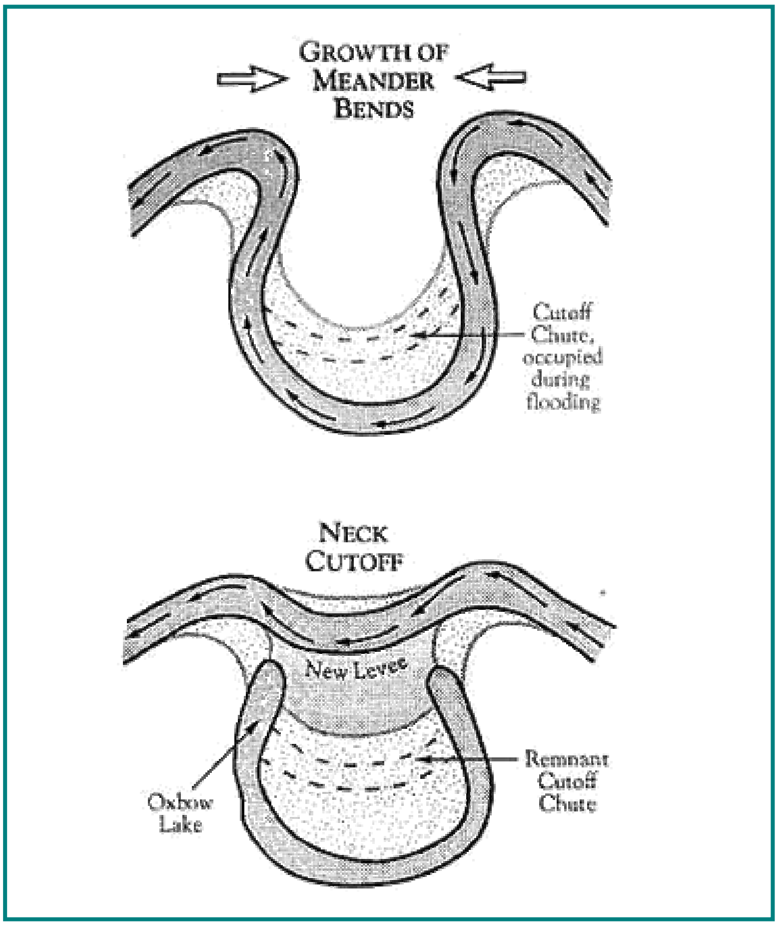


Fig. 6.2 - The Process of Meander Abandonment

Although meander growth seems like a unidirectional process but it can only expand to the width of the valleys before encountering more resistant bedrock. A variety of factors can even lead to abandonment of meander. The lateral expansion eventually cause meander channels to intersect, temporarily re-establishing a shorter and straighter channel and finally cutting off the original channel (Fig. 6.2). Where both ends of these abandoned meander channels are cut off from the newly established channels, they form horseshoe-shaped lakes, known as oxbow lakes (Fig. 6.1). These lakes become sites of accumulation of fine overbank sediments and commonly known as swamp or wetland. A second and perhaps the more common cause of abandonment of meanders is associated with process of neck cut-off (Fig. 6.2 and Fig. 6.3). During flooding, flow across the inside of the point bar can establish channels through the narrow neck between two meanders. Intense scouring of these channels leads to establishment of new channel across the point bar and abandonment of the entire meander (Lewis and Lewin, 1983; Reineck and Singh, 1975; Mount, 1995; Goswami *et al*., 1999).

Another process by which the meandering rivers abandon its entire channel and follow a new route is avulsion. Goswami *et al*. (1999) defined channel avulsion as the sudden and major shift in the position of a channel to a new part of floodplain (first order avulsion) or sudden reoccupation of an old channel on the floodplain (second order avulsion) (Fig. 6.4). It is the main mechanism by which island is excised from extant floodplain. Anabranches are secondary channels in the floodplain that maintain semi-permanent course. During large floods, the flow displaces large proportion of the channel flow to over bank flow across the floodplain and leads to establishment of a new channel in surrounding low-lying areas and termed as avulsion.

Sinuosity index (SI) is used to define meandering. The sinuosity of a river is the reflection of the channel length required to cover a given straight line distance (Fig. 6. 5). It is defined as:

$$SI = L_{cl} / L_r$$

Where, L_{cl} is mid-channel length of the widest channel, and L_r is the straight valley length measured along a straight line (Leopold and Wolman, 1957; Friend and Sinha, 1993). A higher sinuosity means there are meander of either a high wavelength or high frequency or both. For a meandering channel, SI is >1.5.

(b) Dynamics of Braided Rivers

Braided rivers are bedload dominated and tend to have less resistant bank primarily made up of coarse-grained, less cohesive sediment. The channels are more likely to be wider and shallow. During moderate to high discharge events, these rivers establish multiple channels that repeatedly diverge and join (Fig. 6.1). By creating multiple channels, the river increases the effectiveness of bed roughness by increasing the total wetted perimeter.

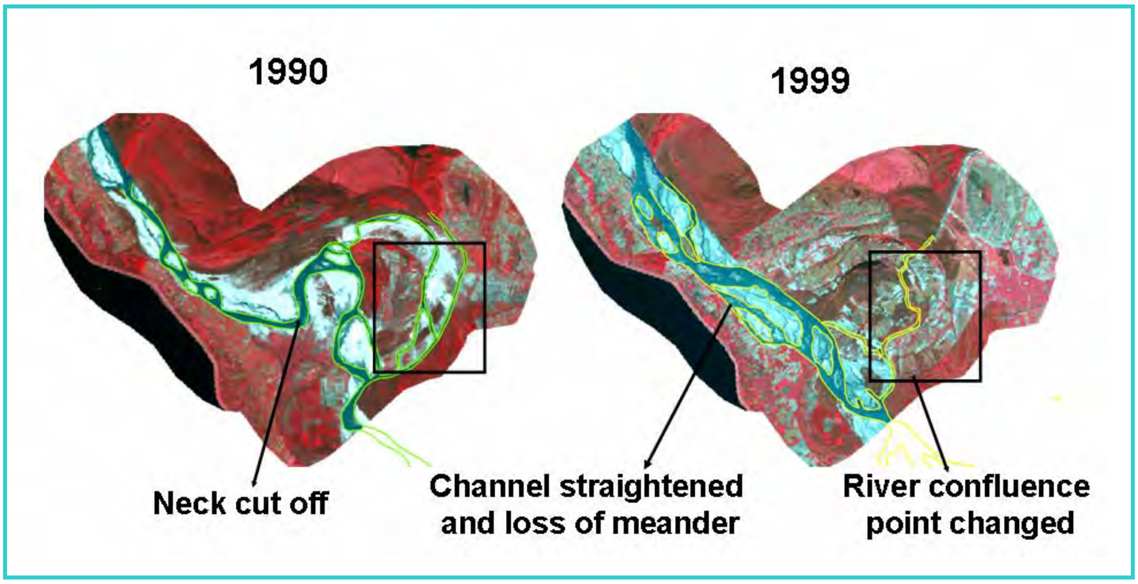


Fig. 6.3 - Satellite Imagery of 1990 and 1999 Illustrating the Episode of Channel Straightening through Neck Cut-off in a Section of Sharda River

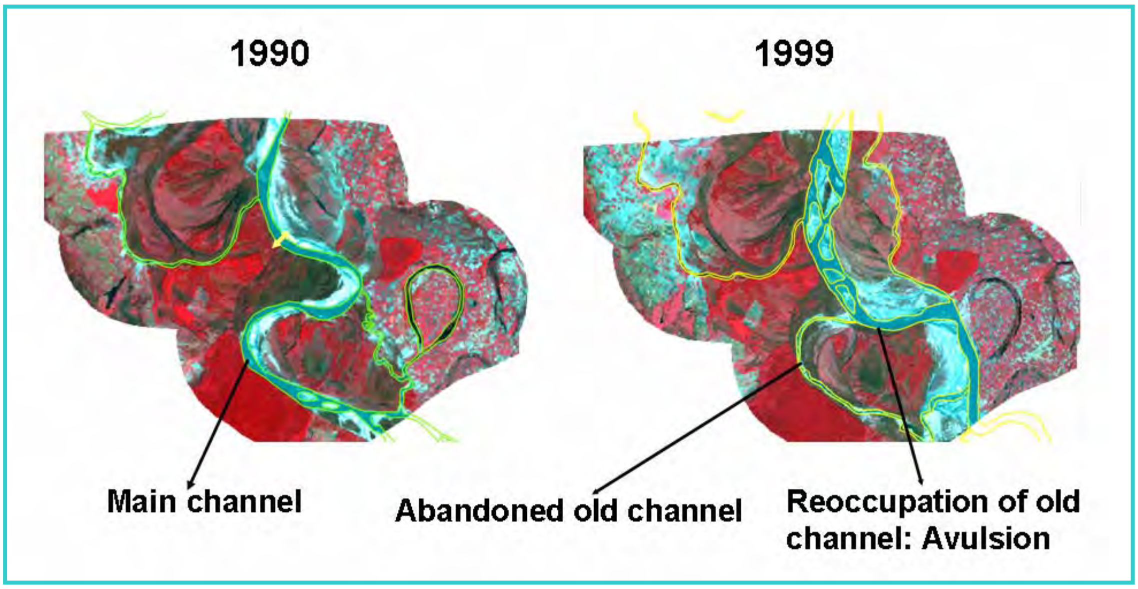


Fig. 6.4 - Satellite Imagery of 1990 and 1999 Illustrating the Episode of Avulsion in a Section of Sharda River

To exacerbate, the channel are typically broad and shallow with numerous sand and gravel bars that further increase bed roughness. Braided river occur when the sediment load transported by the channel becomes greater than its carrying capacity. In order to maintain equilibrium, excess material is dumped in the form of gravel bars, inchannel bars, and islands that divide the flow into number of channels.

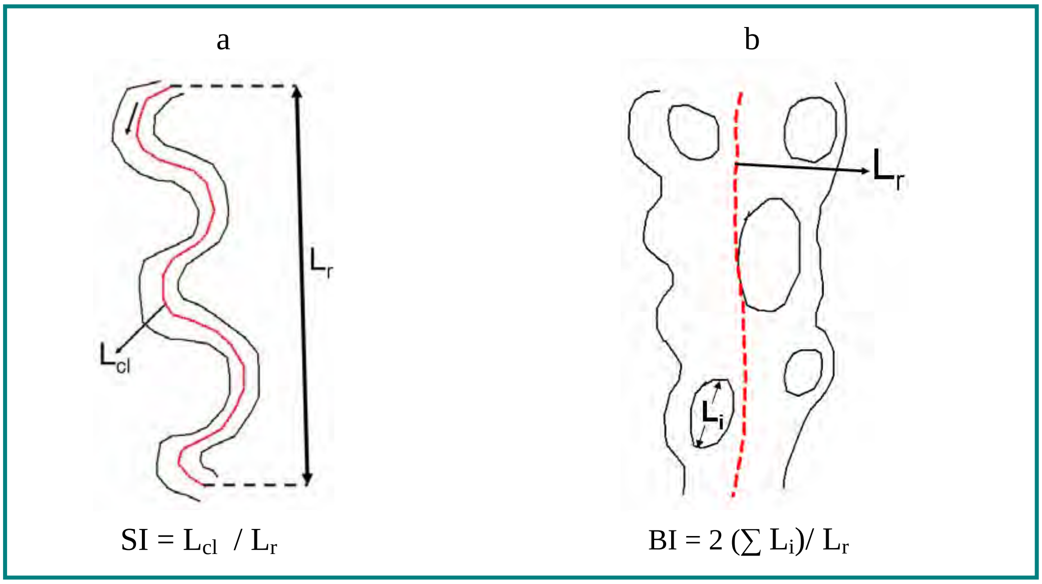


Fig. 6.5 - Calculation of the (a) Sinuosity, and (b) Braiding Index

An important characteristic of braided rivers is the instability of their channels. Channel abandonment can occur on time scales varying from hours to months and can involve either gradual or sudden change. The reason for the dynamic nature is rooted in their varying discharge, overall coarse sediment load, and unstable bank materials.

Brice (1964) used a Braiding Index (BI), which is computed as follows:

$$BI = 2 (\sum L_i)/ L_r$$

Where ($\sum L_i$ is length of all islands and/or bars in the reach, and L_r is the length of the reach measured midway between the banks of the channel belts. For braiding rivers, BI=>1 (Fig. 6.5).

6.1.2 Flow Regulation, Channel Changes, and their Impact

Winterbottom (2000) defined river channel change as variations in form which constitute a departure from a state of dynamic equilibrium. Dynamic equilibrium in a river channel is whereby a channel is adjusted to its discharge regime and although the processes of erosion and deposition continue, the overall form is preserved to produce a dynamically stable pattern (Lewin *et al*., 1988). The true channel change consists of an alternation in channel pattern and form (hydraulic geometry, sinuosity, braiding index, and pattern) that constitute a departure from equilibrium (Hooke, 1977; Winterbottom, 2000; Tiegs and Pohl, 2005).

The response of river channel to human interventions has been well documented (Gurnell, 1997; Li *et al*., 2007). These activities initiate changes in hydrology regime and channel conveyance ability, and may reduce channel stability (Winterbottom, 2000). The impact of flow regulation and land use changes on channel morphology from recent publications are summarized in Table 6.1.

The morphology and behaviour of river channels has long been considered a sensitive indicator of the “state” of any river as well as record of process acting within its watershed (Mount, 1995). Understanding this nature, rates, and causes is particularly important where it threatens priority conservation areas and could cause loss of biodiversity. A better perceptive could help land and resource managers to make decisions that maximize the ecological benefits of flooding (e.g. channel changes results in a mosaic of habitat patches, and successional stages, rehabilitating riparian vegetation and deter the proliferation of exotic species) and minimize damages (e.g. alternation of aquatic and riparian ecosystems, damage to property) (Gilvear *et al*. 1999; Tiegs and Pohl, 2005). The study of historical channel change can prove to be important in understanding altered river dynamics. Only by understanding the past can one place recent and ongoing changes in channel form into perspective and thus begin to unravel the complex factors, which influence the nature of rivers (Winterbottom, 2000).

Table 6.1 - Summary of Land Use Changes and their Impacts on River Channels

Land use changes	Geomorphic response	Study site	Authors
Construction of lateral embankment, reservoir, vegetation encroachment, cessation of wood-cutting and grazing	1945-1991: Change from braided to a single-thread meandering channel; Terrestial like succession due to lowered water table; Landscape diversity decreased	Ain River, France	Marston *et al*. (1995)
Construction of dams, diversion and bank protection structure	1920-1950: Channel narrowing (65%); change from braiding to meandering	Piave River	Surian (1999)
Construction of dam, and activities like dredging, and mining	1950-2000: Riverbed incision; Change in shape and course of the river during high discharge; Reduction in secondary channels width, and length	Jarama River, Central Spain	Uribelarrea *et al*. (2003)
Construction of dams/barrages in the upper reaches	1977-1998: Reduction in discharge; Depletion in riverine forest; Change in course of river	Indus River, Pakistan	Siddiqui *et al.* (2004)
Intensive agriculture and pasture in catchment area	1970-2000: Increase in flooding; Increase in avulsion process	Taquari River, Brazil	Assine (2005)
Reforestation, decreasing agricultural activity and land abandonment	1945-1994: Reduction in discharge and sediment supply to river; Decreased flooding caused narrowing and incision of riverbed lead to terrace formation	Dragonja River, SW Slovenia	Keesstra *et al*. (2005)
Construction of dam, change in flow regime	1945-1989: Change in sinuosity and rates of lateral channel migration; Implications on bald eagle, moose and fish habitat	Snake River, Wyoming, USA	Marston *et al*. (2005)
Deforestation followed by invasion of shrubs and reforestation in late 19th and early 20th centuries	1938-2002: Changes in sediment size; Narrowing of the channel; Decoupling of tributary fan from the main stem	Weraamaia Catchment, New Zealand	Kasai (2006)
Levee construction along the riverbank	1951-1997: Increase in over-bank sedimentation and incision; Channel widening	Jianli reach, Yangtze River, Singapore	Li *et al*. (2007)

6.1.3 Degradation of Riverine Ecosystem

Riverine ecosystem depends to a high extent on natural disturbances, the seasonal hydrological dynamics are crucial for maintaining ecological integrity. Flood control by levees, land drainage, river bed dredging, river regulation by dams and various alterations of the natural hydrological regimes and land use changes disrupt the natural flow regime and isolate rivers from their floodplains and have been the major factors in physical habitat degradation (Petts, 1996; Ward and Wiens, 2001; Jungwirth *et al*., 2002). Flow regulations have fragmented the world's major rivers into disjunct, largely disconnected ecosystems. Mccully (1996) has estimated that approximately 40, 000 large dams (>15 m in height) and over 8,00,000 small dams have been built on rivers worldwide, indicating the pervasive effects of dams on the ecology of rivers (Johnson, 2002).

Numerous studies have measured or forecasted sharp declines in biodiversity downstream of dams and other river engineering work (e.g. Johnson *et al*., 1976; Petts, 1980; Bayley, 1991; Ligon *et al*., 1995; Poff *et al*., 1997; Johnson, 2002; Cosgrove *et al*., 2000; Killeen *et al*., 1998). For example, Cosgrove and Hastie (2001) reported the number of the rivers in Scotland with endangered mussel (*Margaritifera margaritifera*) populations which have been adversely affected by different river engineering activities. According to them, out of 36 rivers, dam construction and flood defense work were responsible for decline in mussel's populations in 16 cases. Killeen *et al.* (1998) also reported the destruction of one entire mussel population in north-west Wales by a dredging operation. Similarly, Siegal *et al*. (1998) also found significant changes in sex ratio, population structure, and body condition in an endangered rattlesnake population after it was subjected to an extensive flood in 1993 which was considered to be result of construction of flood control levees along the Missouri River in USA. Roshier *et al.* (2002) suggested the urgent need to look at landscape perspective on response of waterbird to changing wetland dynamics in wake of increasing pressure for diversion of water or damming for water storage in Australia. On similar lines, Cohen *et al.* (2001) also in their study discussed loss of Colorado River delta, a remnant wetland as a result of upstream impoundments, channelization and conversion of wetland to agriculture.

6.1.4 River Dynamics in Dudhwa Landscape

Besides numerous streams and rivulets, two major rivers – Sharda and Ghaghra are lifeline in Dudhwa landscape as they profoundly influence ecology and the socio-economics of the region. In recent decades, Dudhwa landscape experienced changed patterns in silt load and flow regime in most of its rivers including Sharda and Ghaghra Rivers (Plate 6.1 and 6.2). The reasons believed to be massive land use changes *viz.* deforestation for settlement of people and conversion of land to agriculture in upper reaches along the International border on Nepalese side during 1960s-70s. Additionally, channelization of rivers on the upper reaches has also affected flow regime of the rivers. Heavy deforestation has resulted in enhanced run-off and greater siltation rate, ultimately raising the river bed level which has increased the severity of floods in lower reaches (Plate 6.2 and 6.3).

There is a growing concern among resource managers of Dudhwa landscape about these chaotic changes. Despite the great significance of rivers on the ecological integrity in the region and large scale river channel changes noticed in recent years, the subject of holistic research on river dynamics has been overlooked. The present study aimed to understand the changes in channel pattern in one of the major rivers of Dudhwa landscape i.e. Sharda River and specific objectives are as follows.

6.2 The Objectives

- To understand the channel planform in Sharda River
- To document historical planform changes in Sharda River

Plate 6.1 - Altered River Dynamics in Dudhwa Landscape

Recently, enhanced silt was dredged out of Suheli River, DNP. Excessive silt was raising the river bed causing heavy flooding as well as influencing adjacent habitats

Enhanced silt and heavy flooding caused drying up of Sal and its replacement by *Syzygium cumini*

Soil erosion and gully formation due to heavy flooding in DNP

Plate 6.2 – Dynamics of Sharda River

Annual flooding, silt deposition and channel migration in the Sharda River are few important drivers of the dynamic *Terai* ecosystem in Dudhwa landscape.

In recent decades, changed patterns in silt load and flow regime and sudden change in river course have been noticed in Sharda River.

Enhanced silt gets deposited in abandoned area left due to change in course of River.

Plate 6.3 – Impact of Sharda River

Old Sharda Bridge. Due to change in course of river and excessive silt, bridge is now abandoned.

Silt deposits in the grasslands of forests of NKFD

Embankments have been put up to control the water during heavy flooding.

6.3 Study Area

To study channel planform and channel changes in Sharda River, a length of 60 km stretch from Sharda Sagar reservoir till the river leaves KWS was selected. This length of the river flow through diverse and important riparian areas of Dudhwa landscape as it pass along NKFD and KWS (Fig. 6.6).

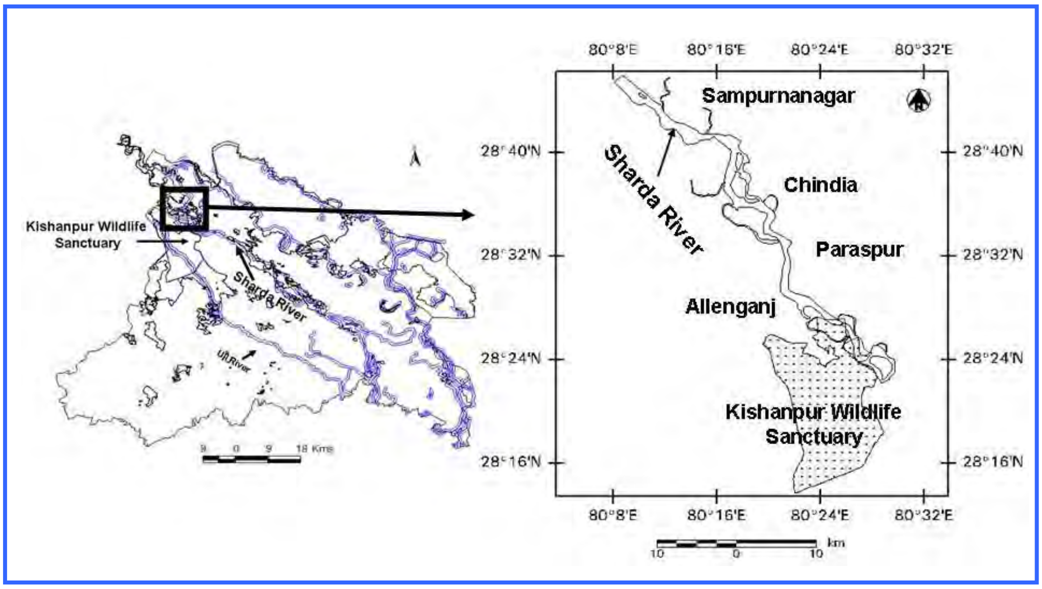


Fig. 6.6 - Location Map of Sharda River with Few Prominent Locations

Sharda River is a meandering river and descends in India from Nepal where it is called Kali River. On its upper course, the river forms India's eastern boundary with Nepal, joins with the Gori Ganga at Jauljibi then Saryu River at Pancheshwar and finally descends in plains.

The tract has very gentle slope to the south-east. The average altitude is 165 m a.m.s.l. The soil consists of the alluvial formation of the Gangetic plains showing a succession of beds of sand and loam. The Sharda River is regarded as the one of the most dangerous rivers during flood seasons because of the susceptible bank condition. Every year, it causes loss of property, structure, and agriculture land. Its lateral movement causes loss of vegetation along the boundry of sanctuary and NKFD. Bank protection measures have been taken in few parts of the channel through construction of boulders and lumbar to strengthen the delicate riverbank. Outside the protected area and along the Sharda, the area has experienced rapid socio-economic development and increase in human population. Swamps and grasslands created in abandoned areas (old channels, oxbow lakes, and vast alluvuim deposits by migrating Sharda River) as a result of change in course of Sharda get encroached by people and reclaimed into agricultural lands. There are continuous attempts to put more and more area under plough (De, 2001; Kumar *et al*., 2002).

6.4 Methodology

Data acquisition and image processing**:** For assessing spatial changes of channel over a longer period of time, satellite images from 1977 (Landsat MSS – resolution 80m), 1990 (Landsat TM – resolution 30m), 1999 (Landsat ETM+ – resolution 30m), and 2001 (IRS 1D, LISS III – resolution 23.5m) were used. All images were from October except the 1977 Landsat MSS image, which was from March. Channel changes were studied *via* assessing channel characteristics i.e. change in channel morphology, bank line position, length, area, sinuosity, and braiding intensity. In order to assess characteristics, all datasets were geometrically corrected and resampled to bring to the same scale.

Channel characteristics**:** The river channel was digitized in GIS as one continuous polygon for each year at a scale of 1:50,000. River channel was defined as an elongated area where streamflow occurred with sufficient frequency, force and duration to preclude the presence of vegetation such that 90% or greater of the area is bare ground or water (Gurnell, 1997; Winterbottom, 2000; and Tiegs and Pohl, 2005).

Change in morphology**:** In order to study the nature and amount of bank line shift, the digitized river channel of 2001 was divided into 6 almost equal segments (A to F) of 10 km each (Fig. 6.7). The channel reach between the starting point and section 1-1 was designated as segment A, between section 1-1 and 2-2 as segment B and so on. For assessing significant changes in banklines of river channel in each segment during different time periods of

1977-1990, 1990-1999, and 1999-2001, a combined map was prepared by superimposing the digitized river channels (Fig. 6.8 and Fig. 6.9).

***Amount of bankline shift*:** Each of six segments were again divided into two equal halves, and the amount of bankline shift was measured at 13 transversed sections (1-1, 1'-1'…..6-6, 6'-6') as illustrated in Fig. 6.7.

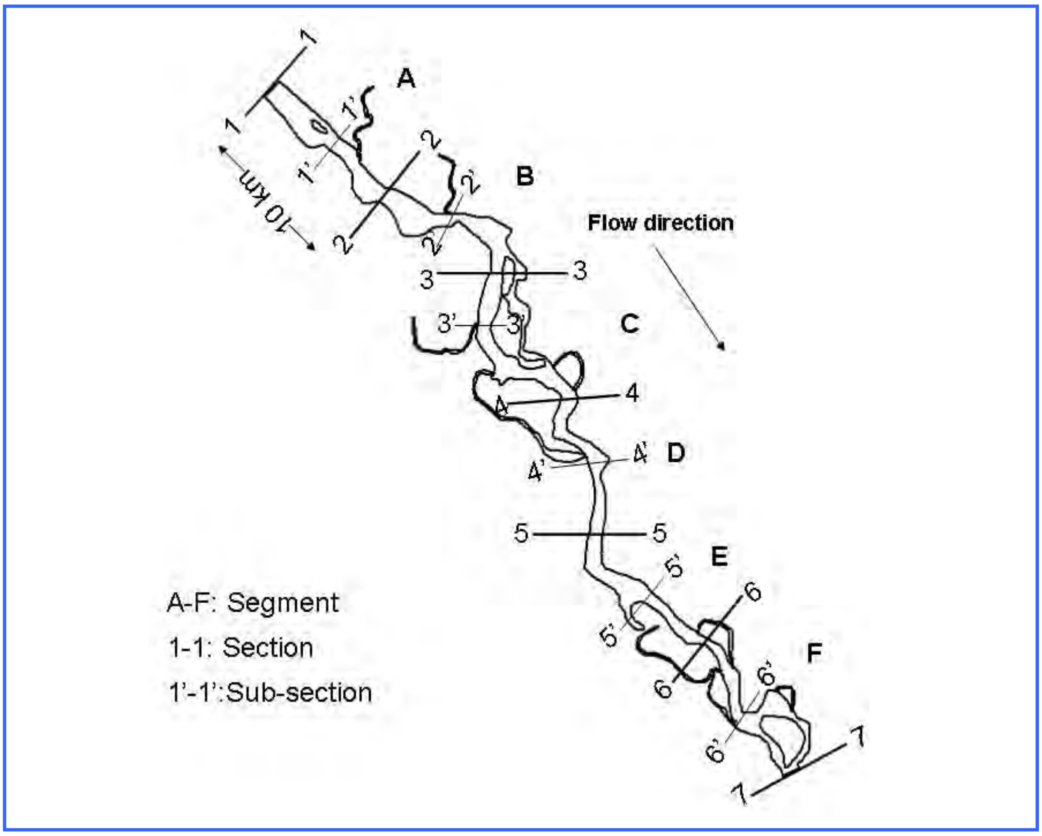


Fig. 6.7 - Channel Course of Sharda River Showing the Transverse Sections and Segments

***Changes in channel length, area, sinuosity, and braiding intensity*:** Channel length was measured along the line equidistant and parallel to left and right banks. Active channel area was determined for each polygon, excluding vegetated mid-channel islands >1.5 sq km as adopted by Tiegs and Pohl (2005). The line used to determine channel length was also used to measure sinuosity. Channel length, area, sinuosity, and braiding intensity were determined for entire river channel for all the assessment periods and also for each segment to exemplify the channel pattern at different reaches.

Braiding intensity could not be calculated for the year 1977 due to difference in month of satellite data.

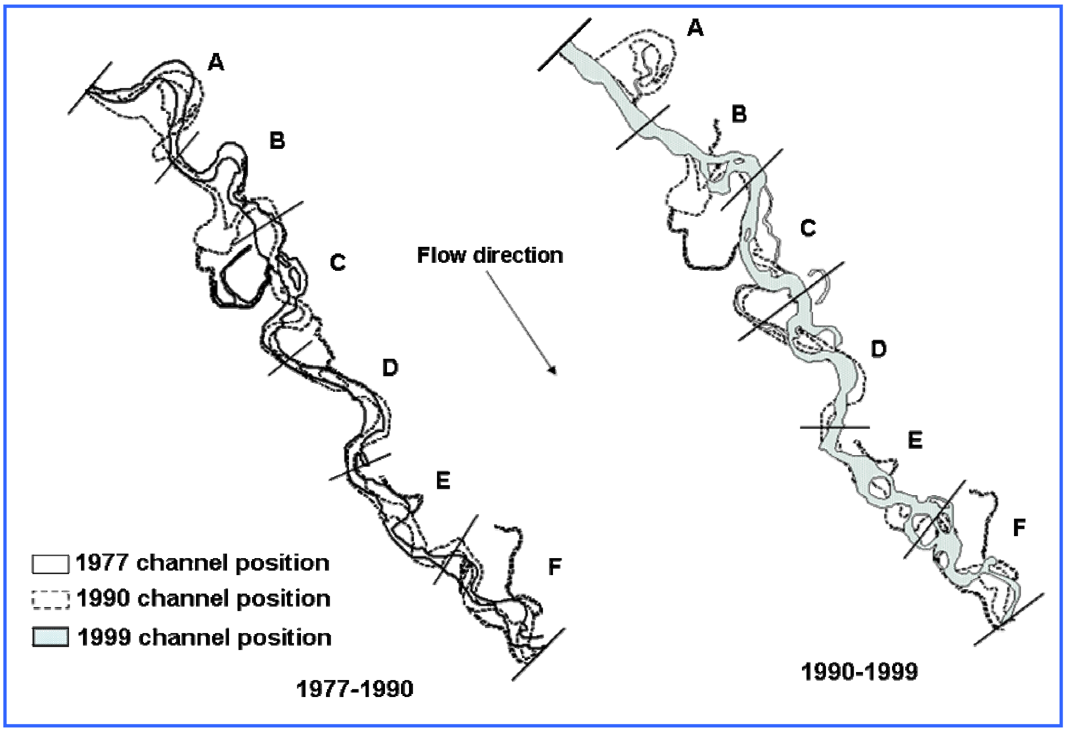


Fig. 6.8 - Channel Planform Change for the Study Area (1977-1999)

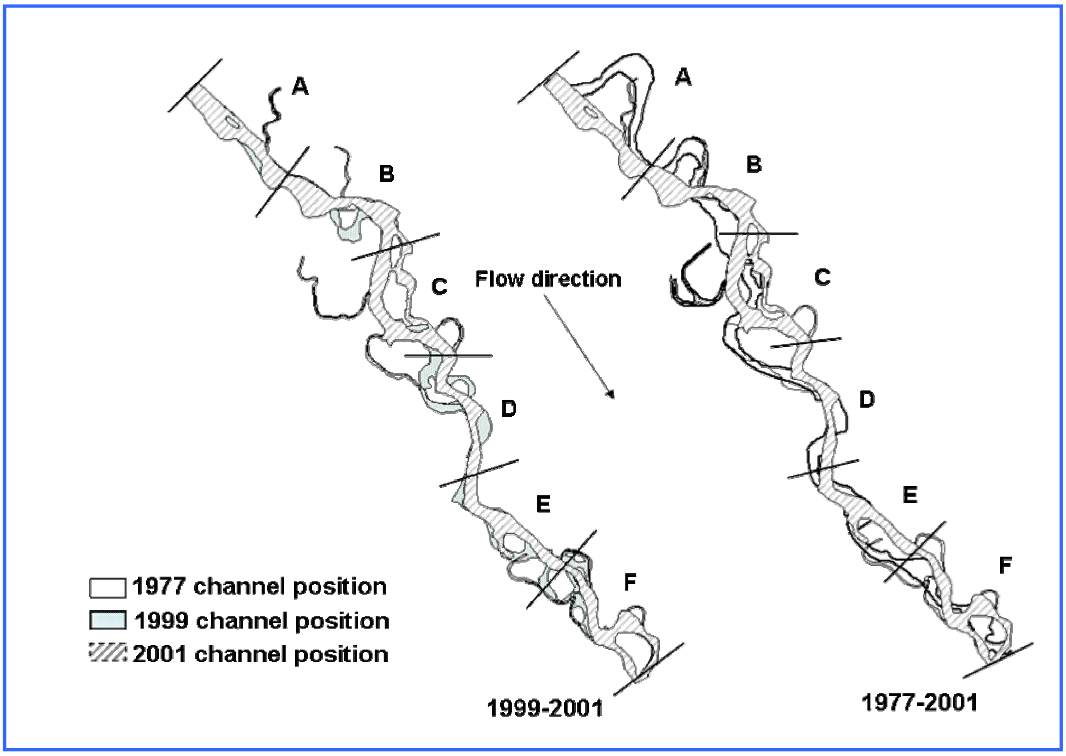


Fig. 6.9 - Channel Planform Change for the Study Area, 1999-2001 and Overall 1977-2001

6.5 Results

The planform changes that have taken place in the Sharda River from Sharda Sagar reservoir to KWS over a length of 60 km as in 2001 during the 24 years assessment period from 1977 to 2001 were varied, and in some cases chaotic in nature. Broad based changes observed were grouped into four categories as described by Goswami *et al*. (1999). These are:

a) Alteration in the direction of flow due to neck cut-off
b) Widening of the river channel
c) Development or abandonment of anabranches
d) Progressive shifting of the meander bends

Above broad based planform changes in Sharda River during the overall assessment period (24 years: 1977-2001) and other three shorter assessment periods viz. (13 years: 1977-1990; 9 years: 1990-1999, and 2 years: 1999-2001) intervened within the overall assessment period are described below. This is followed by description on changes in morphology in all the six segments (A to F), amount of bankline shift, and changes in sinuosity, braiding intensity, and channel area.

6.5.1 Planform Changes in Sharda River

The four types of planform changes that have taken place in studied channel of Sharda River are described below one by one.

(a) Alteration in the direction of flow due to neck cut-off

In the beginning of assessment period i.e. year 1977, there were eight well defined meander bends within the studied channel of the river. By 1990, one case of neck cut off was observed in segment B. It led to abandonment of the meander loop and development of another in new direction of the channel flow. During the next assessment period (1990-1999), three cases of straightening of the river course due to neck cut-off occurred in segment A, B, and E (Fig. 6.3 and Fig. 6.10). The straightening decreased the length of the channel by 3.8, 2.7, and 1.6 km in A, B, and E segments, respectively. Additionally, the overall decrease in the total length of the river by 15.3 km from 1990 to 1999 was recorded (Table 6.2).

Only one case of straightening of channel in segment D due to neck cut-off was observed in period 1999-2001. The reduction in length was minimal. A significant event of channel widening due to initiation of neck cut-off just with the cut in the meander neck and development of new channel was recorded in 2001.

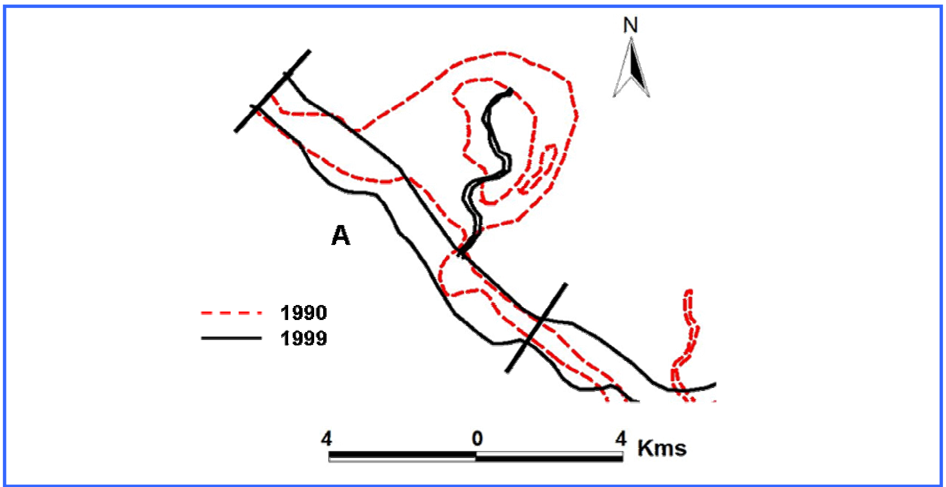


Fig. 6.10 - Straightening of Sharda River in Segment A by 1999 due to Neck Cut-off and Change in Confluence Point of Tributary

Length (km)				
Year	**1977**	**1990**	**1999**	**2001**
Segment				
A	15.5	13.8	10.0	10.1
B	12.4	14.3	11.5	10.4
C	09.7	11.9	10.8	10.2
D	13.5	14.7	10.2	09.9
E	11.8	12.5	10.9	10.1
F	10.9	12.6	12.7	11.2
Total Length	73.8	79.8	64.5	61.9

Table 6.2 - Channel Length at Different Segments of the Sharda River

(b) Widening of the river channel

In addition to reduction in channel length, there have been cases of channel widening. The period between 1990 and 1999 registered four cases of channel widening in segment B, D, E, and F which also represent maximum cases of channel widening in the entire time frame of study (Fig. 6.11). The widening was due to migration of bankline or development of mid-channel islands. The assessment periods of 1977-90 and 1999-2001 recorded only one and two cases of widening, respectively.

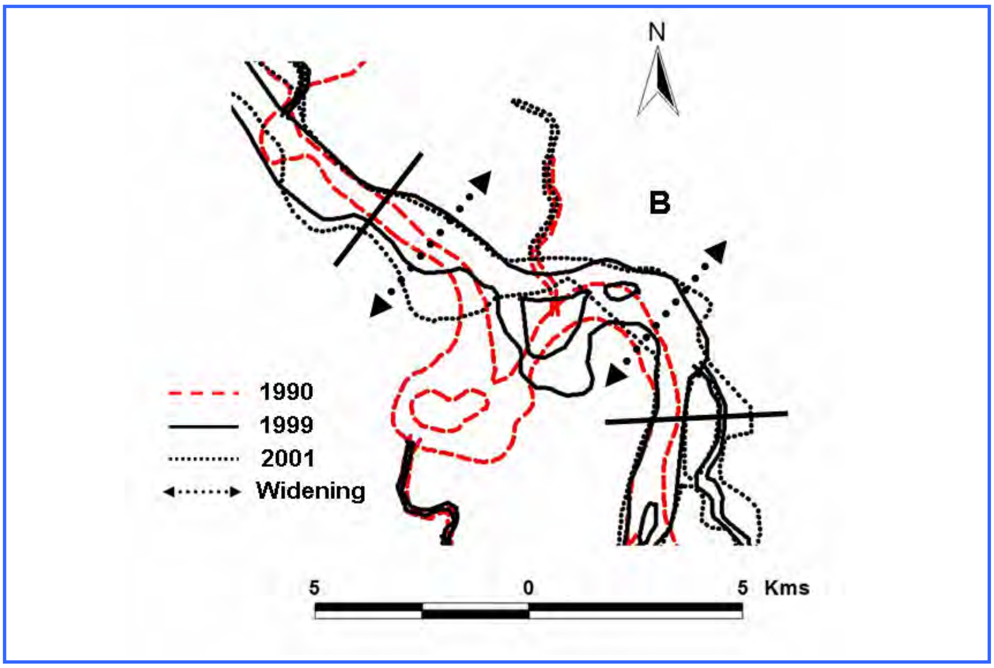


Fig. 6.11 - Progressive Widening of the Sharda River Channel in Segment B from 1990-2001

(c) Development or abandonment of anabranches

Emergence of new anabranches and abandonment apparently due to avulsion are two important changes shown by Sharda River during the assessment periods. The period between the year 1977 and 1990 saw the emergence of two new anabranches in segments B and C. Both connected the newly formed meander to main channel. Segment E registered one case of avulsion wherein the channel abruptly changed its flow direction and shifted to a new position.

By 1999, two new anabranches appeared in segments A and C. In segment A, prior to 1990, a tributary of the Sharda joined the main channel through a meander. By 1999, meander got abandoned due to neck cut-off and thus the tributary had to traverse 5.8 km through a newly formed anabranch to join the main channel (Fig. 6.3, 6.10). In segment C, avulsion forced the major portion of the flow to the anabranch formed during the period of 1977-90. In 1999, the earlier main channel behaved as an anabranch (Fig. 6.4, 6.12).

During the assessment period of 1999-2001, the main channel widened in segment C. It forced the anabranch formed during 1990-99 to become its part leading to the loss of an anabranch. The process excised two islands from the floodplain. Another considerable change of this period was registered in lower part of segment E. In image of 1999, the main channel was found widened due to appearance of three islands. In span of two years i.e. till 2001, the flow got constricted to the middle portion and islands became part of adjacent vegetation extracting two anabranches on east and west banklines.

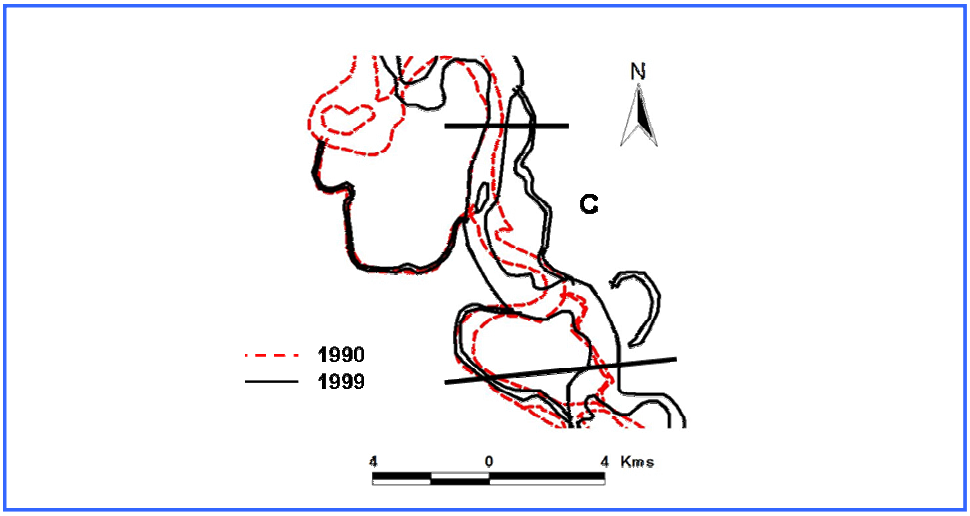


Fig. 6.12 - Avulsion in Segment C of the Sharda River Forced the Flow to an Anabranch in 1999 and Earlier Main Channel Behaved as an Anabranch

(d) Progressive shifting of the meander bends

Progressive shifting of meander bends is an inherent property of a meandering alluvial river by virtue of which it tends to maintain equilibrium in energy distribution (Goswami *et al*., 1999). Most of the changes observed in meanders in different periods conformed to three types of movement i.e. extension, enlargement, and lateral migration (Fig. 6.13).

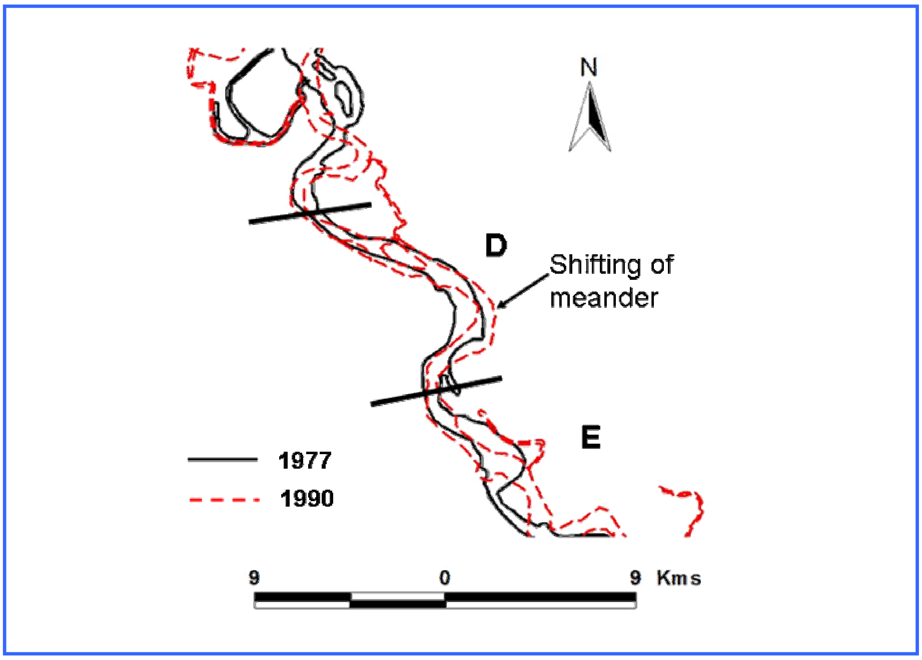


Fig. 6.13 - Progressive Shifting of the Meander Bends in Sharda River

6.5.2 Changes in Channel Morphology

Sharda River experienced pronounced changes in the channel morphology during the study period. The following section describes the changes segment wise:

(a) Segment A

Significant changes occurred during the first phase of assessment period (1977-1990) in segment A. The process of neck cut-off just started which caused significant increase in width of channel. The new widened channel then followed the straight path and joined the older direction of flow in segment A only. The widened channel also developed a new island by 1990. Observation during the second phase of assessment period (1990-1999) revealed that the process of neck cut off got completed by 1999 (Fig. 6.10). It compelled the river to follow in the straight path in southward direction and led to abandonment of earlier meander. A tributary of the Sharda used to join the main channel through this meander, the abandonment caused it to traverse 5.8 km ahead to join the main channel in 1999. No significant changes were observed in the third and last phase of assessment (1999-2001).

(b) Segment B

By 1990, there was loss of a meander in segment B apparently due to neck cut-off. The channel was forced to flow in south-west direction through a newly formed meander. The channel also lost width slightly. Another important change by 1990 was the appearance of a new anabranch which joined newly formed meander with segment C. The neck cutting off continued during the period 1990-1999. The earlier formed meander was abandoned and channel followed the straight path. The channel widened slightly offsetting the loss in preceding period. An island also appeared in 1999 and despite loss of meander; anabranch formed during 1977-1990 period still existed as dead arm in 1999. The significant changes during the last phase of assessment (1999-2001) were the persistent widening of the channel, attachment of the earlier formed island to the adjacent vegetation and appearance of a new island (Fig. 6.11).

(c) Segment C

Observations on the images of 1977 and 1990 indicated that the channel became more sinuous by 1990. It shifted to north-east sweeping away vegetated area. An anabranch also appeared in 1990 which connected a meander to segment D. By 1999, avulsion diverted the major portion of the flow towards north-east through anabranch formed during the period of 1977-90. The earlier main channel then behaved as an anabranch (Fig. 6.10). Another new anabranch also appeared by 1999. During the assessment period of 1999-2001, the main channel widened. It forced the anabranch formed during 1990-99 to become its part. The process excised two islands from the floodplain.

(d) Segment D

During the first phase of assessment, the only notable change was shifting of channel towards north-east slightly and appearance of an island. The island formed in 1990 got enlarged by 1999 and divided the flow into east and west channels. The position of the meander shifted slightly towards north-east. By 2001, the channel straightened due to neck cut-off and made its way through the middle of the island. The reduction in length was minimal.

(e) Segment E

In 1977, the flow of the channel was observed towards south-west, near to a village. In 13 years separating 1977 and 1990, the channel flow shifted towards north-east, away from the village. By 1999, the channel widened due to the presence of new island and it again came close to the village. Another discernible change is the straightening of the channel in the lower part of the segment due to neck cut off and division of the straightened channel into segments due to appearance of three islands by 1999. In span of two years, till 2001, the flow got constricted to the middle portion and islands became part of adjacent vegetation extracting two anabranches on east and west banklines.

(f) Segment F

The channel of 1990 was more sinuous as compared to 1977. The west bank line through a meander came close to the boundry of KWS and swept away Sal forest patch by 1990. The shifting of the meander continued till 1999 as evident in the image of 1999. By 1999, the west bankline bordered the KWS and swept away vegetation. A significant event was observed in the image of 2001. The process of neck cut-off just started with the cut in the meander neck and development of new channel which widened the entire channel.

6.5.3 Amount of Bankline Shift

Changes in bankline shift are presented below, firstly for three shorter assessment periods and secondly for the overall period of 24 years.

(a) Assessment period: 1977-90

There has been substantial shift of west bankline during the period of 1977-90, maximum being apparently 2.85 km at subsection 1’-1’ followed by 1.6 km and 1.5 km at sections 3-3 and 6-6 (Table 6.3). The major shift at subsection 1’-1’ towards west caused marked increase in channel width between segment A and B. On the other hand, at section 3-3, the shift was toward east and with lesser outward movement of east bankline, it caused channel narrowing. Another narrowing took place at subsection 5’-5’ but here both the banklines contributed equally. Eastward migration of both banklines occurred at section 6-6 and 7-7.

(b) Assessment period: 1990-99

During the assessment period of 1990-99, there were many instances of westward shifting of both banklines. At subsection 1’-1’, neck cut-off process got completed by the year 1999 and both banklines shifted towards west. Outward migration of east bankline at section 1-1 caused widening of channel. At subsection 3’-3’ and section 6-6, both banklines showed westward migration whereas at subsections 4’-4’ & 5’-5’ only west bankline registered westward migration. Eastward migration was registered by both banklines at section 5-5 (Table 6.3).

(c) Assessment period: 1999-2001

Contrary to the previous assessment period, in short span of two years, marked eastward migration of both banklines at section 4-4, subsections 5’-5’ and 6’-6’ with maximum being at section 4-4 occurred. There were two instances of narrowing at subsection 2’-2’ and section 6-6 and one instance of widening at section 3-3 (Table 6.4).

Table 6.3 - Shift in Banklines of the Sharda River During Assessment Periods 1977-1990 and 1990 - 1999

Period	1977-90		1990-99	
Section/Subsection	**West Bank**	**East Bank**	**West Bank**	**East Bank**
1-1	0.17 W	0.00	0.10 E	0.68 E
1’-1’	2.85 W	0.19 E	Abandoned	-
2-2	0.11 W	0.18 W	0.15 W	0.24 E
2’-2’	Abandoned	-	Abandoned	-
3-3	1.58 E	0.08 W	-	0.16 E
3’-3’	Abandoned	-	1.45 W	1.29 W
4-4	0.40 W	0.52 W	Abandoned	-
4’-4’	0.54 E	0.30 E	0.59	0.19 W
5-5	0.24 E	0.16 W	0.61 E	1.09 E
5’-5’	0.41 E	0.47 W	0.64 E	0.20 E
6-6	1.54 E	1.38 E	2.33 W	0.61 E
6’-6’	0.82 W	0.60 W	0.00	0.30 W
7-7	1.40 E	1.46 E	0.16 E	0.21 W

(d) Overall Assessment period: 1977-2001

The overall change indicated eastward migration of channel during the entire assessment period. The maximum eastward shift was registered by west bankline at section 7-7 of about 2.0 km. There were only two instances of westward migration of channel at sections 2-2 and subsection 6’-6’. Outward movement of west bankline towards west at section 2-2 caused widening of the channel (Table 6.4).

Table 6.4 - Shift in Banklines of the Sharda River During the Period 1999-2001 and 1977-2001

Period	1999-2001		1977-2001	
Section/Subsection	West Bank	East Bank	West Bank	East Bank
1-1	0.11 W	0.18 E	0.15 W	0.78 E
1'-1'	0.11 W	0.15 E	Abandoned	-
2-2	0.25 W	0.04 W	0.48 W	0
2'-2'	2.38 E	0.37 E	0.87 E	0.89 E
3-3	0	0.37 E	1.50 E	1.67 E
3'-3'	0.10 E	0	0	0.72 E
4-4	0.92 E	0.94 E	Abandoned	-
4'-4'	0	0	0	0
5-5	0.19 E	0	0.94 E	1.01 E
5'-5'	0.52 E	0.31 E	0.29 E	0
6-6	2.39 E	1.11 W	1.60 E	0.85 E
6'-6'	0.49 E	0.46 E	0.60 W	0.30 W
7-7	0.26 W	0	2.07 E	1.68 E

6.5.4 Changes in Sinuosity, Braiding Intensity, and Area

Intensity of meandering (sinuosity) was computed in Sharda River during different assessment periods. Values of sinuosity oscillated considerably in six segments during different assessment periods. In 1977, two segments of the channel (A and D) were characterized by sinuosity value of 1.5 indicating a meandering pattern (Table 6. 5). In subsequent assessment period, albeit the original meandering segment A lost its sinuosity value by 11% but there was a gain of 9% by the other segment D along with gain in all the segments. Maximum gain, being 32% was registered in the segment C. In next assessment periods, there was continuous downfall in values of sinuosity. During the period of 1990-99, the sinuosity decreased in all the segments except F. The maximum registered loss was 31% in segments B and D followed by 27% in segment A. The next assessment period (1999-2001) also experienced downfall with slight gain in segments A and B. While considering the entire stretch of Sharda River, changes in channel configuration led to an overall decrease in sinuosity by 15% in 24 years i.e. from 1977 (1.36) to 2001 (1.15) as revealed in Table 6.6. The most significant period responsible for this loss was during 1990-1999.

The investigated stretch of Sharda River also showed braiding of varying amount during various assessment periods. Values varied from 1.51 to 1.78. The braiding index value of 1.78 computed for 2001 came out to be relatively high (Table 6.6).

Table 6.5 - Sinuosity Values at Different Segments of the Sharda River (Values in Parentheses Indicate Percentage Change from Previous Year to Next Year)

Sinuosity				
Year / **Segment**	**1977**	**1990**	**1999**	**2001**
A	1.56	1.39 (-11)	1.01 (-27)	1.02 (+01)
B	1.42	1.64 (+15)	1.13 (-31)	1.19 (+05)
C	1.00	1.32 (+32)	1.20 (-09)	1.13 (-06)
D	1.53	1.67 (+09)	1.15 (-31)	1.12 (-03)
E	1.25	1.32 (+06)	1.15 (-13)	1.07 (-07)
F	1.11	1.28 (+15)	1.29 (+01)	1.14 (-12)

Table 6.6 - Overall Changes in Channel Characteristics of the Sharda River During 1977-2001

Channel Characteristics	Year				Overall change (1977-2001)
	1977	**1990**	**1999**	**2001**	
Sinuosity	1.36	1.48	1.19	1.15	Overall decrease (-15%)
Braiding Index	-	1.51	1.42	1.78	Increase in 2001
Area (sq km)	68.2	76.01	73.57	74.01	Overall increase (+8%)
Length (km)	73.8	79.8	64.5	61.9	Overall decrease (-16%)

River dynamics also influenced the channel area during different periods of assessment (Table 6.7). The value of channel area ranged from minimum of 7.92 sq km in period 1999-2001 (segment D) to 23.87 sq km in period 1977-1990 (segment A). The maximum gain of 87% occurred during the period of 1977-1990 in segment A. The gain could be attributed to widening of the channel due to starting of neck cut-off. The next notable gain was in the period from 1999-2001 in segment C again due to widening. The other significant gains observed in different segments were: (a) in segment C (42% during 1999-2001), (b) in segment E (36% during 1990-1999), and (c) in segment F (27% during 1990-1999). On the other hand, the significant losses recorded were as follows: Maximum (53%) was in segment A in period 1990-1999 due to straightening of channel due to neck cut off; followed by 36% in segment C during the period of 1977-1990 period due to loss of width (Table 6.7). The Sharda River registered an overall net gain of 8% in channel area over 24 years (Table 6.6).

Table 6.7 - Changes in Channel Area at Different Segments of the Sharda River (Values in Parentheses Indicate Percentage Change from Previous Year to Next Year)

Area (sq km)					
Year / Segment	1977	1990	1999	2001	Overall (% change)
A	12.76	23.87 (+87)	11.23 (-53)	13.64 (+21)	(+07)
B	11.36	11.78 (+04)	12.36 (+05)	13.84 (+12)	(+22)
C	11.44	07.34 (-36)	10.42 (+42)	16.31 (+56)	(+43)
D	11.62	11.88 (+02)	11.68 (-02)	07.92 (-32)	(-32)
E	10.03	10.82 (+08)	14.74 (+36)	10.66 (-28)	(+06)
F	10.99	10.32 (-06)	13.14 (+27)	11.64 (-11)	(+06)

6.6 Discussion

The first time study on river dynamics in Dudhwa landscape provided valuable baseline information on channel characteristics and changes over past 24 years. Changes in channel characteristics and management implications of such changes are discussed in the following section:

6.6.1 Changes in Channel Characteristics

This study uses the satellite imageries of different periods to understand the channel changes in the Sharda River during the period of 24 years. Analysis of planform changes pointed that Sharda River faced pronounced changes from 1977 to 2001. The changes had been varied and chaotic. The results indicated the incessant increasing instability of the river. The 13 years that separated the period of 1977-90 registered only one neck cut-off and avulsion followed by three neck cut-off and one avulsion during subsequent nine years between 1990 and 1999. However, the short span of 2 years between 1999 and 2001 even recorded one neck cut-off and one avulsion and also recorded the initiation of another neck cut-off. Mount (1995) has associated neck cut-off and avulsion to heavy flooding. Thus, this increasing instability pointed towards increase in sudden water discharge from upstream. Also he elucidated that with the increase in the frequency of the flooding, depositional, rather than erosional processes act to expand the channel capacity and when discharge exceeds the channel capacity of the river, there is a dramatic increase in cross-sectional area associated onto the floodplain. Thus, the above argument of increased flooding in Sharda River was further supported by an overall net increase in the channel area.

Assessment of planform changes segment-wise pointed that segments B and E had been most active segments within 60 km stretch as notable changes occurred in every assessment period. In segment B, neck cut-off was dominant process whereas in segment E, avulsion was prominent. Roy and Sinha (2005) while exemplifying the process of change in the channel morphology at the confluence point of Ganga - Ramganga Rivers in Gangetic plains, India during the period of 1970-2000 have also found analogous results i.e. the development of meanders followed by neck cut-offs and avulsions as main processes. They also noticed that neck cut-off was always accompanied by an increase in sinuosity. On the contrary, in the present study, reduced sinuosity was recorded in all the neck cut-offs except in segment B during 1977-1990.

Another notable outcome was eastward movement of the channel during the entire assessment period. On the contrary, west bank line had been more unstable as compared to east bankline in all assessment periods. The maximum amount of bankline shift was observed at subsection 1’-1’ in west bank line during 1977-90 to initiate the process of neck cut-off. During the entire timeframe of the study, both banklines at section 6-6 had been unstable making significant shifts. Raj *et al*. (2004) also observed that the course of the Vishwamitri River, a meandering river of Gujarat has shifted towards east between 1969 and 2003. They inferred that eastward tilting of the area is responsible for eastward migration of the Vishwamitri River.

Low value of sinuosity value in all the segments during different periods led to straightening of the channel and reduction in the channel length. The overall decrease in sinuosity and increase in braiding intensity was found during the study period indicate high rate of sediment supply. Goswami *et al.* (1999) also found decrease in overall sinuosity with increase in corresponding braiding intensity during 1920-1990 in Subansiri River, Assam, India. They concluded that river channel seems to make a change from meandering pattern in 1920 towards braiding pattern by 1990 and that the extra amount of sediment came in as revealed by increased braiding intensity which must had choked the river gradually and initiated bank erosion and consequently led to channel widening. This argument by them also seems to be applicable in the context of Sharda River as overall decrease in sinuosity and increase in Braiding intensity accompanied by enhanced channel area were observed. Findings of Goswami *et al.* (1999) and the present study support the findings of Burkham (1972). He suggested that over a longer period of time scale braiding develops as a result of historic flooding. Friend and Sinha (1993) have also described the negative correlation between sinuosity and braiding in three different types of river (Gandak River: Braided; Burhi Gandak River: Meandering; Baghmati River: Braided/Meandering) of North Bihar in India.

6.6.2 Management Implications

The management is proposing the construction of levees along the Sharda River bank to control the flow during major floods to prevent loss of riparian vegetation, important wetlands within KWS and loss of agricultural land, and structure and property from flood disaster. A recent study by Li *et al*. (2007) attempted to assess the changes in Jianli reach of Yangtze River in China due to levee construction. They observed that during 50 years, even under the constraint of levees, the channel underwent a minor widening due to frequent bank failures during major flooding. They also concluded that levees construction changed the erosion/deposition pattern with increase in overbank sedimentation and river incision. They further explained that the bank protection measures restrict the width of the channel; more stress comes up on the riverbed, which is more vulnerable than protected riverbank causing scouring of the bed. The restriction also amplifies the bank full discharge and thus the flow does not flush down immediately leading to increase in flood retention time which benefits the sedimentation over the floodplains.

Present study clearly indicates that the Sharda River has undergone a drastic change in past 24 years and its equilibrium is constantly being disturbed. The study found that the period during 1990-99 to be most influential in causing the discernible changes as maximum number of neck cut-off, maximum loss of length, and initiation of drop in sinuosity started during this very period. Another important finding is the eastward migration of the channel but west bankline to be more unstable indicate that forests of KWS and NKFD which lie along the west bankline to be more prone to flooding in future due to likely sudden channel shifts.

The increasing instability, braiding intensity and channel area together pointed towards the changing flow regime and sediment dynamics of the upstream region. The reasons could be incessant land use changes and river engineering works upstream. The relative importance and effect of these man made activities with respect to the channel dynamics require primary attention, and it is proposed as a subject of further research.

In gist, the present study made significant contribution towards the baseline information on the dynamics of major Sharda River influencing the ecological integrity and socio-economic in Dudhwa landscape. Study could also highlight its increasing instability in recent 2-3 decades and resultant drastic changes in channel planform.

Chapter 7

The Landscape – Floodplain and Conservation of Swamp Deer

7.1 The Floodplain

A ‘floodplain’ or ‘flood plain’ is flat or nearly flat land adjacent to a stream or river that experience occasional or periodic flooding. It includes the ‘floodway’, which consists of stream channel and adjacent areas that carry flood flows, and the ‘flood fringe’ which are areas covered by the flood, but which do not experience a strong current (Encyclopaedia Britannica, 1911). Floodplains are broad valley of alluvium deposits carried and set down by fluvial processes (erosion, transport, deposition) of the present day river as it migrates laterally (Kellerhals and Church, 1989; Schnitzler, 1997; Ward, 1998). Water is hence the dynamic component of the alluvial landscape that distributes energy, material, and information across and through the plain. Fluxes of water, sediments, and energy are both longitudinal (upstream to downstream) and transerval (from the river to the edges of the plain and *vice versa*). Water movements are also vertical, with infiltration within the sediments of the plain and circulation among them (Amoros and Petts, 1993; Schnitzler, 1997). Channel pattern effectively stratifies the dynamics of rivers and floodplains (Beechie *et al*., 2006). The floodplain serve as an important part of the river itself, acting as a check value to absorb high flows or flood pulses, as kidney to cleanse runoff waters, as a mechanism of energy exchange, and as temporary and seasonal habitats for biological components (Junk *et al*., 1989). Floodplain-river ecosystems are natural fragmented systems because of periodic hydrological connections (Thorns *et al*., 2005).

Floodplains belong to the most complex and species rich ecological systems (Ward *et al*., 1999; Jungwirth *et al*., 2002; Dziock *et al*., 2006). They support rich ecosystems in quantity and diversity. High level of spatio-temporal heterogeneity is responsible for such species-rich environments. Indeed, floodplain ecosystems are unique as they provide necessary conditions to support an intermediate habitat – the ‘flood zone’, between the terrestrial and aquatic habitats. The flood zone is alternatively wet and dry during high and low flows (Lubinski, 1999).

7.1.1 Floodplain Biodiversity

Natural disturbance (fluvial action) induced by flooding is major contributor for maintenance of biodiversity on floodplain. Flooding renews nutrients, reduces anaerobic conditions, increase sediment diversity, and opens new patches for colonization. As the river channel migrates laterally across the floodplain, a diverse array of lotic, semi-lotic, and lentic environments are formed by fluvial actions. These environments include side channels, dead arms connected with the main channel at one end, abandoned meander loops, abandoned braids, swamps, and marshes, in addition to tributary streams. Thus, results in a mosaic of habitat patches, ecotones, and successional stages, characterised by different biotic community.

The fauna of riverine ecosystem comprises a mix of obligate terrestrial to aquatic species even a mammal such as elephants (Ward *et al*., 1998; Dudgeon 2000). According to Robinson *et al.* (2002), important aspects of dynamic riverine ecosystem for animals include habitat mosaics (faunal-habitat diversity relationships), environmental gradients that meet varying habitat requirements during complex life cycles (habitat species successional patterns, reproduction and nursery areas), refugia and fragmentation (population sustenance, genetic maintenance, diversity of species traits), corridor dynamics (migration and dispersal pathways), fauna-habitat feedbacks (ecosystem engineering, faunal distribution and successional mosaics in faunal assemblages). Dudgeon (2000) lists nine species of Primates, 17 species of Carnivora (otters, cats), four species of Cetacea (e.g. river dolphin), four species of Perissidactyla (e.g. rhinoceros), 14 species of Artiodactyla (e.g. deer), one species of Lagomorpha (rabbit), and one species of Proboscidea (elephant) for tropical Asian floodplains.

Historically, human have used rivers more than any other type of ecosystem (Arthinton and Welcomme, 1995; Jungwirth *et al*., 2002). According to Sparks (1995), most of the world's 79 large river-floodplain ecosystems have been altered by human activities. As a result, very few of the world's large rivers retain their original functional integrity. The degradation of rivers and riverine landscapes including floodplains is increasingly being recognized as a crucial political issue with socio-economic repercussion (Niaman *et al*., 1995).

The relationship between channel dynamics and hydrology on the one hand, and floodplain vegetation mosaic, on the other hand, has been addressed by several groups of researchers (Marston *et al*., 1995). The most comprehensive review on this topic is provided by Naiman and Decamps (1990), Amoros and Petts (1993), and Malanson (1993).

Understanding the impact of altered river dynamics on floodplain ecosystem is critical, especially for priority conservation areas. Changes from equilibrium could cause the loss of permanent or transient habitats for many faunal species leading to their dispersal, population decline, or even extinction from that particular area. Thus, assessment of altered river dynamics and its effect is vital for management, mitigation and restoration of wildlife habitat, populations, and other conservation values (Schnitzler, 1997; Ward, 1998; Pedroli and Harms, 2002).

There is paucity of comprehensive works documenting implications of channel migration with respect to its impact on areas of conservation significance or habitats of threatened species. In one of the studies, Marston *et al.* (2005) found that changes in the water release schedule of Jackson Lake Dam on the Snake River near Grand Teton National Park, U.S.A., triggered changes in river channel sinuosity and rate of lateral channel migration. They also concluded that these changes in the Snake River and its floodplain have direct implications on habitats of bald eagle, moose and fish. Cohen *et al.* (2001) discussed loss of Colorado River delta, a remnant wetland as a result of upstream impoundments, channelization and conversion of wetland to agriculture.

Parihar *et al.* (1986) have assessed the changes in land areas in Kaziranga National Park, Assam, India due to channel changes in Brahmaputra River which forms the northern boundry of the park and have discussed its effect on the habitat of endangered Great Indian one horned rhinoceros (*Rhinoceros unicornis*). Pandit and Yadav (1996) have described the channel changes in the river Torsa flowing through Jaldapara Wildlife Sanctuary, West Bengal and its adverse effect on the structure and composition of tall grassland habitats those were once annually flooded by river. Shift of channel from the western side to the eastern side of the sanctuary was recorded in recent decades. Grassland habitats in the western side were earlier predominately used by Rhino (*Rhinoceros unicornis*) prior to the shift of the channel.

7.1.2 *Terai* Ecosystem and Endangered Swamp Deer

Fluvial action is one of the most important disturbance agents in *Terai* ecosystem, effecting spatial pattern and organization of plant communities by altering soil-moisture gradient with bank cutting and changing channels characterizing it as a mosaic of woodland-tall grassland-wetland complex (Seidensticker, 1976). Tall grasslands occur along the swamps or *taals* which are formed in old channels and oxbow lakes left behind by shifting river course. These open areas are quickly colonized by variety of grass species. If new growth escapes the scouring of the next monsoon, a few years will see the open mud flats becoming tall grasslands (Sanquist and Sanquist, 1988).

A few scattered, surviving remnants of *Terai* ecosystem support a small population of endangered and obligate species of tall grasslands i.e Northern race of swamp deer (*Cervus duvauceli duvauceli* Cuvier) locally known as ‘Barasingha’.

The Northern swamp deer is endemic to the Indian subcontinent and is listed in the IUCN Red Data Book of threatened species as endangered. It was once abundant throughout the tall wet grasslands of the northern Indian and Nepalese *Terai* at the base of the Himalaya range. Factors implicated in its decline include loss of habitat due to conversion of grasslands into agricultural land and relentless hunting (Qureshi *et al.*, 2004). Currently, the northern swamp deer is found in isolated pockets in a few well-protected national parks and wildlife sanctuaries in India and Nepal. In Nepal, about 1,600 animals occur in Suklaphanta Wildlife Reserve in south-west Nepal, and the population in nearby Royal Bardia National Park is estimated to be 50-100 animals. On the Indian side of the border between Suklaphanta and Royal Bardia National Park, Dudhwa Tiger Reserve (DTR) in Uttar Pradesh state supports a single large population of 1,200 – 1,400 animals (Qureshi *et al.*, 2004). Within DTR, Jhadi *taal* (lake) is a stronghold of about 400 animals (Forest Department, Uttar Pradesh) and key to the survival of northern swamp deer in India today (Plate 7.1).

Jhadi *taal* is a pocket of tall grassland around a shallow seasonal lake within the Sal forest of Kishanpur Wildlife Sanctuary (KWS). The *taal* area is typical of the woodland-grassland-wetland complex characteristic of the *Terai* ecosystem (Plate 7.1). It is located on the floodplain of the Sharda River, which forms the northern border of KWS. The changing patterns and major shifts in the Sharda River have brought its channel dangerously close to Jhadi *taal.* Apprehensions are if the changing course and erosion continue, Jhadi *taal* will be inundated or drained by the Sharda River, destroying this prime habitat of swamp deer and likely leading to their local extirpation in the KWS.

Above background has amply highlighted that Jhadi *taal* is a priority conservation site for endangered swamp deer in the floodplain of Sharda River while the previous chapter has illustrated the highly dynamic nature of this river, particularly during past 20-30 years. Hence, it is pertinent to assess implications of channel changes on Jhadi *taal* and the species of concern i.e. swamp deer.

7.2 The Objectives

Present study, therefore aims to evaluate channel changes in a stretch of the Sharda River and its implications on an area of high biodiversity value i.e., Jhadi *taal* in KWS. Study objectives included: (1) describe river channel

Plate 7.1 – Distinctive Characteristics of Jhadi *taal*, KWS

Jhadi *taal*, it is a pocket of tall grassland around a shallow seasonal lake within the Sal forest of Kishanpur Wildlife Sanctuary. It is located on the floodplain of the Sharda River

Jhadi *taal* supports a small population of endangered and obligate species of tall grasslands i.e Northern swamp deer (*Cervus duvauceli duvauceli* Cuvier) locally known as 'Barasingha'.

Jhadi *taal* attract large number of migratory birds during winter and thus with KWS has been recognized as an Important Bird Areas by Islam and Rahmani (2004) changes and determine their effects on swamp deer habitat and on floodplain pattern from 1948 to 2001; and (2) construct a probability model of channel configuration during the timeframe of the assessment period to assist managers in assessing channel stability in the study area and risk of channel encroachment to Jhadi *taal*.

7.3 Study Area

An approximately 10 km stretch of the Sharda River along the northern boundary of KWS, including Jhadi *taal*, was selected as the study site (Fig. 7.1). This stretch is a part of F segment described in the previous chapter. The details of the study area have already been explained including Sharda River, KWS, and Jhadi *taal*.

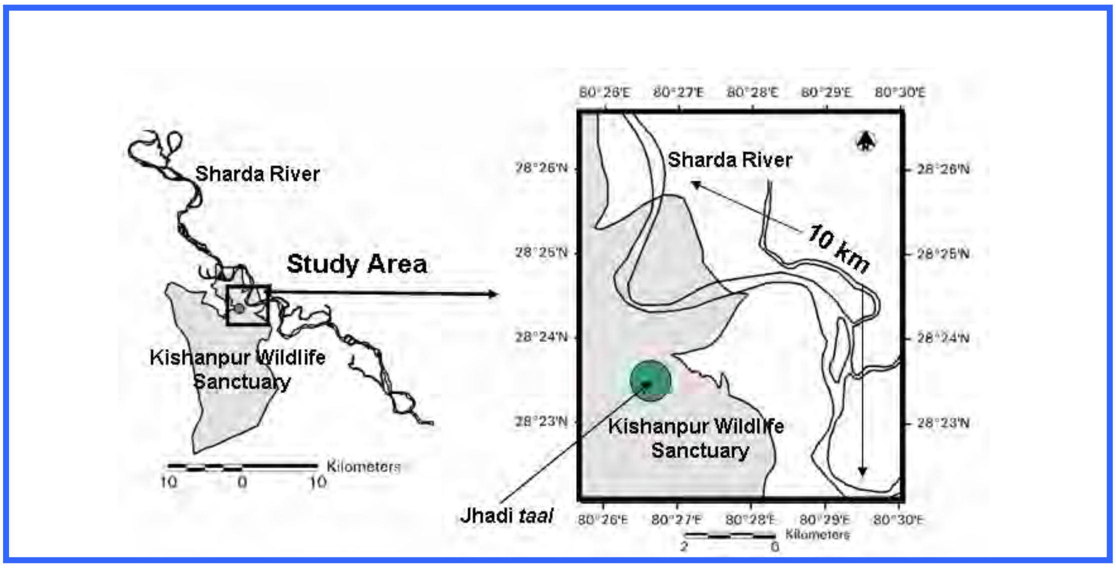


Fig. 7.1 - Showing Jhadi *taal* in Kishanpur Wildlife Sanctuary and Adjacent Floodplain of Sharda River

KWS and Jhadi *taal* are not only famous for swamp deer but they have also been recognized as Important Bird Areas (IBA) and placed under A1 category, i.e., holding species classified as globally threatened with extinction (Islam and Rahmani, 2004). According to De (2001), KWS and Jhadi *taal* also support a large population of tiger due to abundant prey that includes swamp deer, hog deer and wild pig.

Outside the sanctuary and along the Sharda River, swamps and grasslands created in abandoned channel areas (old channels, oxbow lakes, and vast alluvuim deposits by migrating Sharda River) usually get encroached by local farming communities and reclaimed into agricultural lands (De, 2001; Kumar *et al.*, 2002).

7.4 Methodology

The methodology deployed for assessment of channel changes, floodplain vegetation, and the development of a Locational Probability Model are described one by one:

7.4.1 Channel Changes

Details on the type of data acquired, image processing, and channel characteristics quantified in the present study are presented below:

(a) Data acquisition and image processing

The study could acquired toposheets of the year 1948 (1:63,360) and 1965 (1:50,000) produced by the Survey of India for the select stretch of Sharda River. Again same satellite images from 1977 (Landsat MSS – resolution 70m), 1990 (Landsat TM – resolution 30m), 1999 (Landsat ETM+ – resolution 30m), and 2001 (IRS 1D, LISS III – resolution 23.5m) as described in Chapter 6 were used. All images were from October except the 1977 Landsat MSS image, which was from March. Database were geometrically corrected and resampled to bring them to the same scale. The study section was delineated on the 2001 LISS III digital image, and within the studied section, a fragment of floodplain (41.3 sq km) for assessing the effect of channel changes on vegetation development was also delineated. The 1977 Landsat image was not used for the preparation of a land use/cover map, for reason already stated. Also, the 1965 toposheet was not available for the entire study area, so for that period, channel boundaries were extrapolated to estimate channel length, area and sinuosity (Tiegs and Pohl, 2005). The land use/cover map could not be prepared for 1965 too.

(b) Channel characteristics

The methodology for assessing the channel characteristics (change in bank line position, channel length, sinuosity, channel area and island number and area) for this stretch is similar to given in the previous chapter. In order to describe and compare the channel characteristics during different periods of assessment, the studied section of channel was divided into three segments named as ‘A’, ‘B’, and ‘C’ (Fig. 7.2). In order to assess change in bank line position, the distances to west and east bank line from a common reference point located on Jhadi *taal* were measured for each assessment year.

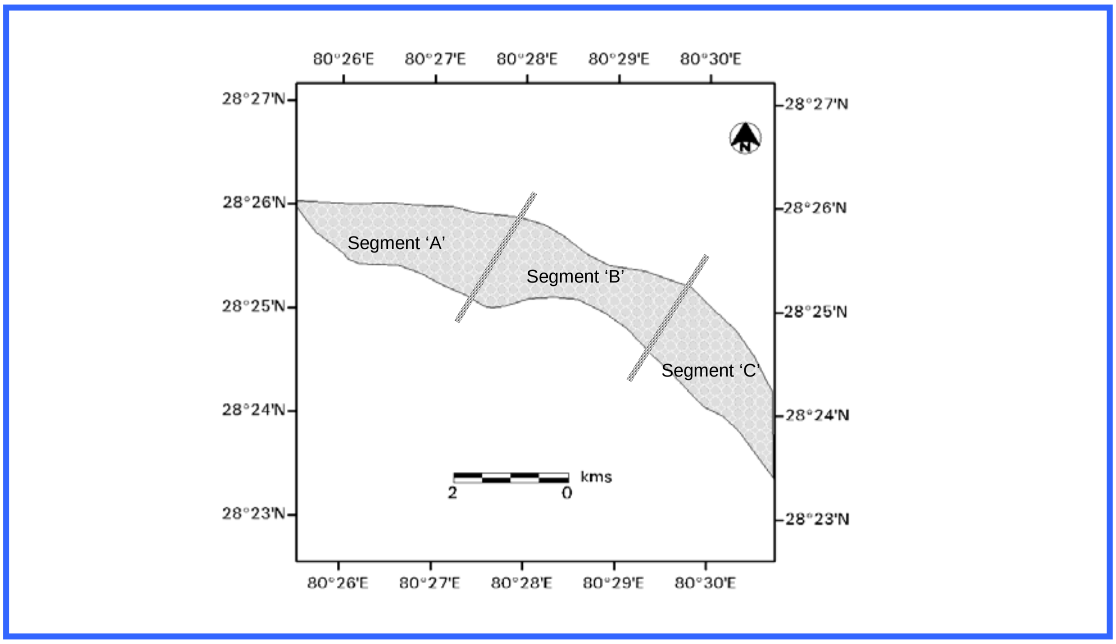


Fig. 7.2 - Showing Channel Sections of the Sharda River

7.4.2 Floodplain Vegetation

Dynamics of floodplain vegetation was assessed using land use/cover maps of different periods.

***Field survey and vegetation mapping*:** Field surveys were undertaken to validate maps during the winter of 2005. Data was collected on the dominant plant life forms at 250 GPS point locations throughout the study area. Land use/cover maps of the year 1948, 1990, and 2001 were prepared through visual interpretation at 1:50,000 scale. The islands were not included as a part of the land use/cover map as they were considered during analysis of channel characteristics. The classified images were overlaid to quantify changes in vegetation and land use/cover categories.

7.4.3 Locational Probability Model

A Locational Probability Model (LPM) as described by Wasklewicz *et al.* 2004 was developed which depicts the most likely location and configuration of the channel in any randomly selected year. The LPM is estimated by overlaying channel area polygons (GIS coverages) where numerical weight (W_n) was assigned to each polygon. The GIS coverages for each year were converted to a raster-based format and assigned each cell a value of 1 or 0, where 1 indicated channel presence and 0 indicated no channel.

The next step was assignment of weight to each polygon. These weighting values were according to the estimate of amount of time each active channel configuration persisted. Graf (2000) represented this weighting method with the following algebraic expression:

$$W_n = t_n/m$$

where W_n is the weighting value assigned to map n, t_n is the number of years separating given map from preceding map; and m is the total number of years for the historic record. Weights were determined from a random year of 2004 as described by Wasklewicz *et al.* (2004). For example, from 1948 to 1965, there is 17-year difference from the total of 56 years (1948-2004). Since 17/56 is equal to 0.3, the 1948 coverage map was assigned a weight of 30.3%.

The final locational probability map was generated by combining the coverages of each year consisting of a value for occurrence and non-occurrence of river channel in each cell and a weight assigned based on the aforementioned method. Each value of cell (*p*) of final locational probability map was based on the algebraic equation developed by Graf (2000) and modified by Wasklewicz *et al.* (2004). Accordingly,

$$p = (W_1F_1) + (W_2F_2) + \ldots\ldots\ldots (W_nF_n)$$

where p is the final locational probability, W_n is the weight assigned to map n and F_n is the channel occurrence or non-occurrence based on the value zero or one. The final map of channel locational p values was shown in classes. Low probability indicates 'instability' while high probability indicates 'stability' of the channel. Based on this, low probability class (1-<33%) occupied area was designated as unstable area, >33-66% class occupied area was referred as moderately stable while high probability (>66-100%) occupied area was classified as stable.

7.5 Results

Findings on the channel characteristics, floodplain vegetation, and LPM are presented below one by one:

7.5.1 Changes in Channel Characteristics

Changes assessed in channel characteristics (bank line position, channel length, sinuosity, channel area, and island number and area) on a select stretch of 10 km of Sharda River during 1948-2001 are described below:

(a) Changes in bank line position

The west bank line shifted by 3.1 km south-west towards Jhadi *taal* during the assessment period (1948-2001). The maximum shift of 1.5 km occurred between 1948 and 1965 (Table 7.1, Fig. 7.3). In 2001, the distance of the west bank line from Jhadi *taal* was reduced to only 100 m (Fig. 7.3). In contrast, the east bank line remained more stable during the assessment period. A significant shift of 1.7 km to the south-west occurred between 1965 and 1977, but was later compensated in 1999 with a reverse shift of 0.7 km back towards north-east (Table 7.1).

Table 7.1 - Distance of Jhadi *taal* from the West and East Banks of the Sharda River Channel from 1948 to 2001. The Values in Parentheses Indicates the Change in Distance in Relation to Preceding Year

Year	West Bank line (km)	East Bank line (km)
1948 (Base Year)	3.2	4.1
1965	1.7 (-1.5)	4.6 (+0.5)
1977	1.2 (-0.5)	2.9 (-1.7)
1990	1.6 (+0.4)	2.5 (-0.4)
1999	1.1 (-0.5)	3.2 (+0.7)
2001	0.1 (-1.0)	3.2 (0.0)
1948 – 2001 (Overall change)	**(-3.1)**	**(-0.9)**

(b) Changes in channel length and sinuosity

The channel length and sinuosity oscillated considerably from 1948 to 2001. Major changes in the channel configuration led to an overall increase in length by 3% and consequent increase in sinuosity by 15%. The most significant period responsible for this overall increase was between 1965 and 1977 when length and sinuosity both increased by 37% and 39%, respectively which represented their highest increase during this study (Table 7.2). Another notable period was during 1990 to 1999 when channel attained its maximum sinuosity value of 1.31 (Table 7.2).

Table 7.2 - Channel Length, Sinuosity, Area, and Island Number and Area in the Sharda River from 1948 to 2001. Values in Parentheses are the Percentage Change in Relation to the Preceding Year

Year	Length (km)	Sinuosity	Area (sq km)	Islands	
				No.	Area (sq km)
1948 (Base Year)	8.83	1.02	5.7	7	5.5
1965	08.10 (-08)	0.93 (-09)	12.3 (+55)	5	5.0 (-09)
1977	11.14 (+37)	1.29 (+39)	12.1 (-15)	4	3.0 (-40)
1990	9.69 (-13)	1.26 (-02)	9.4 (-22.3)	1	0.8 (-73)
1999	10.11 (+04)	1.31 (+04)	10.4 (+11)	1	0.4 (-50)
2001	9.06 (-10)	1.17 (-11)	11.2 (+08)	1	3.9 (+875)
Difference (1948-2001)	**0.23 (+03)**	**0.15 (+15)**	**5.5 (+96)**	**6**	**1.6 (-29)**

(c) Changes in channel area

Similarly as length and sinuosity, channel area also oscillated during the assessment period with a significant net gain of 96%. The maximum gain occurred during the period between 1948 and 1965 when the channel area increased by more than double i.e. 55% (Fig. 7.3). Channel area decreased for the next two subsequent assessment periods and then again started increasing to add to net gain (Table 7.2).

(d) Changes in island number and area

The net loss of six islands and 29% in their area occurred during the entire assessment period (Table 7.2). The number and area of islands kept on decreasing almost in the entire time frame but maximum loss of three islands and 73% area occurred during 1977 to 1990. A short but significant period which offset the continuous decline in island area was from 1999 to 2001 when the area got considerably increased by 875% due to formation of single new island with large area of 3.9 sq km (Fig. 7.4).

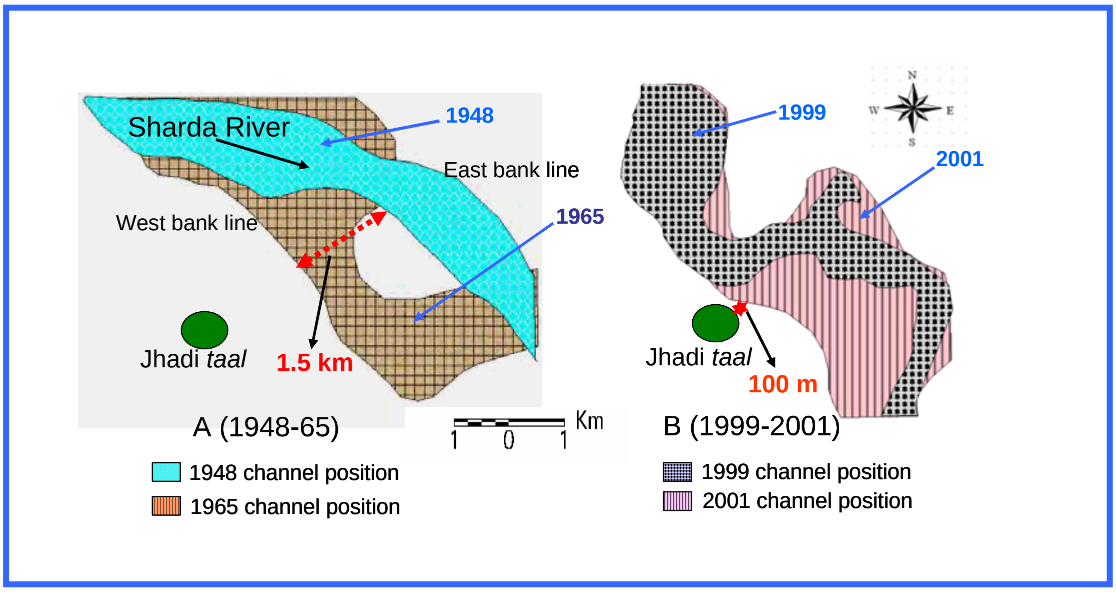


Fig. 7.3 - Notable Periods of Channel Shift that Brought the West Bank Line of Sharda River Close to Jhadi *taal* Occurred During (A) 1948-65 and (B) 1999-2001

7.5.2 Floodplain

Following land use/land cover categories were delineated:

1) Sal Forest occurred on high alluvial terraces with loamy soils that supported an overstory of *Terminalia alata*, *Lagerstromia speciosa*, *Mallotus philippensis* and *Miliusa velutina.*

2) Mixed Deciduous Forest was dominated by *Mallotus philippensis*, *Syzygium cumini, Trewia nudiflora, Dalbergia sissoo, Ficus racemosa,* and *Acacia catechu*.

3) Grasslands occurred in low lying areas or depressions which were water logged and marshy. Prominent grasses were: *Saccharum spontaneum, Sclerostachya fusca, Phragmites karka, Arundo donax,,* and *Saccharum narenga.*

4) Khair and Sissoo forest occurred on new sandy alluvium.

5) Agriculture and habitation had crops of rice, sugarcane, and wheat along side rural habitations.

6) Sand bars occurred on newly created silt deposits and were devoid of vegetation.

7) Water was in active channels.

Changes in floodplain were represented by three types of woodland, one category of grassland, and three other land use/cover categories presented in Table 7.3 and are described below one by one:

Table 7.3 - Area of Land Use/Land Cover Categories in Sharda River Floodplain (41.3 sq km) During the Years 1948, 1990, and 2001

Land Use/Cover Categories	1948 (sq km)	1990 (sq km)	2001 (sq km)
Sal Forest	4.8	*	*
Mixed Deciduous Forest	*	2.7	0.6
Grasslands	12.6	9.5	11.3
Khair and Sissoo Forest	*	1.8	0.5
Agriculture and Habitation	8.7	13.9	10.7
Sand bar	0.4	2.7	1.6
Water	8.6	9.5	11.6

** denotes absence*

(a) Changes in woodland (Sal Forest, Mixed Deciduous Forest, and Khair and Sissoo Forest)

Due to the shift of entire channel towards south-west during the 42 years separating 1948 and 1990, complete loss of 4.8 sq km area of Sal Forest on the north-eastern boundary of KWS was registered resulting in disappearance of this category from the study area in 1990 (Table 7.3 and Fig. 7.4). New land cover categories of Mixed Deciduous Forest and Khair and Sissoo Forest with 2.7 sq km and 1.8 sq km area, respectively were noticed in 1990 in the channel abandoned area but in year 2001, both met with major loss due to continued shifting of channel (Table 7.4 and Fig. 7.4).

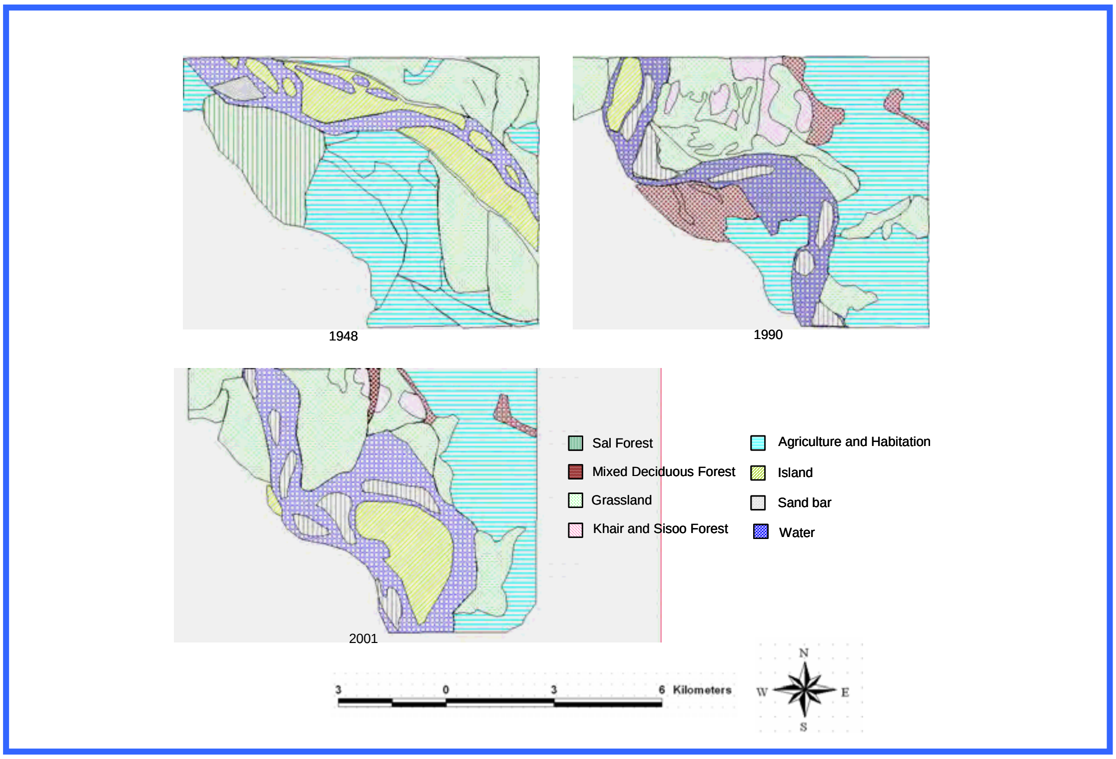


Fig. 7.4 - Land Use/Land Cover Patterns in the Floodplain of the Sharda River Near Jhadi *taal* During 1948, 1990, and 2001

(b) Changes in grasslands

The discernable shift in the channel during the period of 1948-1990 led to loss of 7% of grasslands but this loss was offset by gain during the period of 1990 to 2001. Important grassland habitat suffered a net loss of 3% during the entire assessment period of 53 years (Table 7.4).

(c) Changes in agriculture and habitation

The considerable shift of channel towards south-west during 42 years separating 1948 and 1990 led to loss of large area of habitation and agriculture along KWS boundry (Fig. 7.4). The abandoned area formed on north-east side due to this major shift experienced the expansion of agriculture and habitation to make the net gain during this period to the extent of 12% (Table 7.4 and Fig. 7.4). The continuous shift of the west bank line towards south-west continued during 1990-2001 but in 1999 east bank line made a reverse shift toward north-east (Table 7.1). Both the events led to loss of agriculture and habitation along west and east bank lines leading to net loss of agricultural areas to an extent of 8%. Despite of the major loss during previous assessment period, the net gain in agriculture and habitation during entire assessment period was about 5% (Table 7.4).

Table 7.4 - Areal and Percentage (parentheses) Changes in Land Use/Cover Categories in a 41.3 sq km Area of the Sharda River Floodplain Near Jhadi *taal* Area of KWS

Land Use/Cover Categories	Change in area		
	1948-1990 (sq km)	1990-2001 (sq km)	1948-2001 (sq km)
Sal Forest	4.8 (-12)	*	4.8 (-12)
Mixed Deciduous Forest	2.7 (+07)	2.1 (-5)	0.6 (+02)
Grassland	3.0 (-07)	1.8 (+4)	1.2 (-03)
Khair and Sissoo Forest	1.8 (+04)	1.2 (-3)	0.5 (+01)
Agriculture and Habitation	5.1 (+12)	3.1 (-8)	2.0 (+05)
Sand bar	2.3 (+06)	1.0 (-3)	1.2 (+03)
Water	0.8 (+02)	2.0 (+5)	2.9 (+07)

* *denotes absence of category*

(d) Changes in sand bar and water

The proportion of sand bar and water increased about 3% and 7%, respectively during the entire assessment period. There was continuous increase of water from 1948-1990 assessment period to the next assessment period (Table 7.4).

7.5.3 Locational Probability Model

The Locational Probability Model revealed that 51% of the study area had a low probability of the channel remaining in that location, indicating channel instability. Forty-five per cent of the study area had moderate probability of being continuously occupied by the river channel, thus evincing moderate stability. Only 4% of the area had a high probability of being continuously occupied by river channel, indicating channel stability.

The only stable area of river channel was in segment ‘A’ (Fig. 7.5) upstream from Jhadi *taal*. Unstable channel was identified in all the segments, and the unstable west bank line in segment ‘B’, in particular, indicates continuing instability in the Jhadi *taal* area. Segment ‘C’ had its maximum area under moderately stable category. Two major configuration changes in terms of direction of flow had occurred in segment ‘C’ during the assessment period; otherwise it had occupied the same area in all the years with minor changes.

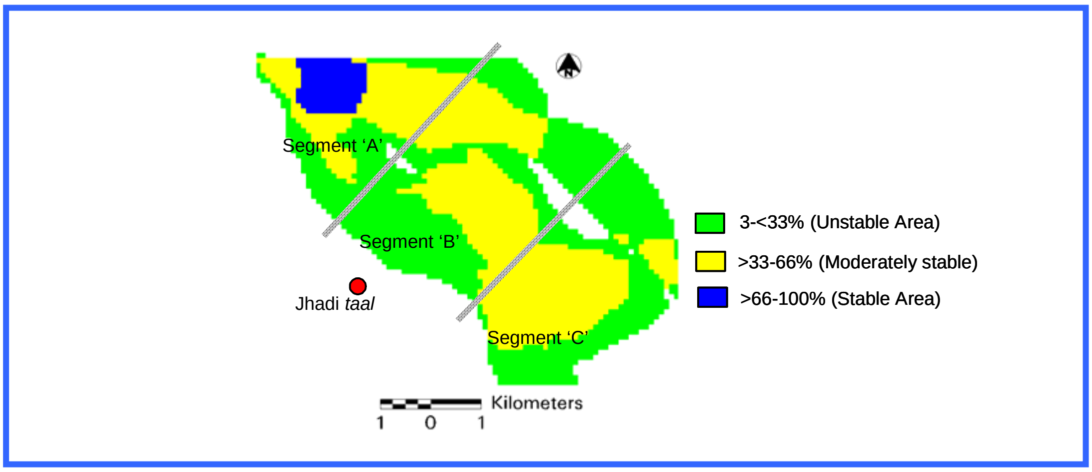


Fig. 7.5 - Probabilities of Channel Stability Based on a Locational Probability Model for the Sharda River Channel Adjacent to KWS

Stable and unstable areas also differed in their size and shape. Unstable areas were elongated and located mostly along periphery whereas the lone stable area was spatially distinct and occupied a small area. Areas classified as moderately stable were of large size and spatially contiguous, but located within two peripheral unstable areas (Fig. 7. 5).

7.6 Discussion

Channel migration of the Sharda River is one of the drivers of the dynamic *Terai* ecosystem in Dudhwa landscape that maintains its unique woodland-grassland-wetland complex. However, rapid river channel changes have made future of Jhadi *taal* and swamp deer precarious.

7.6.1 Implications of Changes in Channel Characteristics

Analysis of channel characteristics distinctly pointed the continuous shift of west bank line towards Jhadi *taal.* Probable reasons for that instability was the presence of agricultural lands and habitations along the western bank of the Sharda River which posed the least resistance to bank erosion and channel expansion. This instability brought the west bank line closer to Jhadi *taal* by 100 m in 2001 and is now posing a potential threat to it.

Another important aspect that analysis pointed was although length and sinuosity oscillated during entire time frame of study but net gain in both pointed that meandering had been increasing in the channel and resulted in major turns and changes in channel configuration. The first noticeable alteration in the assessment period took place during 1948-65 period when area of the channel got double and west bank line shifted towards *taal* by 1.5 km. The second major alteration took place during 1999-2001, again when west bank line moved towards *taal* with massive 1 km shift, channel area also increased but as a new island was formed during this period, only 8% of increase in channel area got registered. Results also revealed that east bank line remained more stable during assessment period. Thus, the study concluded that the west bank line had been relatively unstable as compared to the east bank line and major shifts in the west bank line had been in resonance with drastic increase in channel area. Similarly, Marston *et al.* (2005) found that changes in the water release schedule of Jackson Lake Dam on the Snake River near Grand Teton National Park, U.S.A., triggered changes in river channel sinuosity and rate of lateral channel migration. They also concluded that these changes in the Snake River and its floodplain have direct implications on habitats of bald eagle, moose and fish.

7.6.2 Changes in Floodplain

Assessment on the influence of the channel dynamics on floodplain vegetation and other land use categories revealed net loss in Sal Forest and grasslands, while other land cover categories gained in 53-year of assessment period. The valuable Sal Forest along KWS was the victim of major alteration in channel direction during 1948-65 period. The coming up of Mixed Deciduous Forest, Khair and Sissoo Forest indicated natural succession proceeded on the abandoned areas after the shift of the channel. Forest department also sometime undertake plantation of work of Khair and Sissoo on these abandoned areas to avoid them to get encroached by people.

The increasing trend in water and net gain in sand bar indicated enhanced flooding and more silt coming from upstream. The net gain of 96% in channel area also endorses this statement. In absence of rainfall and flooding data, major flood during periods could not be correlated with channel area and consequent shift in channel direction. The net gain in agriculture and habitation during 1948-90 period despite significant loss along both east and west bank lines was the evidence of encroachment of abandoned area by people.

The grassland showed a slight net loss during the 53-year assessment period. Loss of habitat due to fixed boundaries of protected areas in a dynamic floodplain is same as being faced by management in Kaziranga National Park, Assam, India and other protected areas located on banks of floodplain of rivers. Till recent past, Brahmaputra River formed the northern boundary of the Park and as the river changes its course year after year, the park area was affected by erosion. Thus, Kushwaha *et al.* (2000) found a net loss of 28.5 sq km of park area from 1967 to 1997, and described how newly added area remained largely unutilized as habitat for endangered one-horned rhinoceros (*Rhinoceros unicornis*) for a considerable time.

LPM depicted the presence of stable area only in segment ‘A’. The reason could be confinement of channel by vegetation on both banks in segment ‘A’. The LPM supported observation of threat to Jhadi *taal* in near future by showing the presence of unstable area along west bank line. Tiegs and Pohl (2005) viewed LPM as a Disturbance Probability Model because it depicts how frequently an area will be cleared of its vegetation. Thus, presence of unstable area along west bank line indicates that most likely in near future, channel would again shift from this area and as trend had been more chances are that it will shift towards Jhadi *taal.*

7.6.3 Implications for Conservation

At present, the population of swamp deer in Jhadi *taal* is surviving. However, it is not possible to predict what will happen in near future. If the *taal* gets flooded, it will be total loss of habitat for swamp deer, even if it gets only inundated or drained by cutting of bank by river, it would lead to sedimentation and siltation that would choke the swamp. Ultimately swamp deer would be forced to abandon the area and search for new suitable habitat. Given the present rate of attrition outside the protected area, this remnant population will become vulnerable to poaching, if it tried to look for habitat outside protected area. Several workers have recognized poaching as the main cause of decline in swamp deer population in Dudhwa National Park, also a part of DTR (Sankaran, 1989; Qureshi *et al.*, 2004). They fall prey to poaching when they move out of protected area for seasonal dispersal.

Another mooted issue is that a new suitable habitat eventually may be formed because of channel migration, just as Jhadi *taal* was created as an oxbow lake several years ago by channel migration. However, it may take several years for habitat to develop around a new *taal* and for the recovery of the lost faunal population after a catastrophic loss such as at Jhadi *taal* (Goldman and Horne, 1983). In one such calamity, Hastie *et al.* (2001) reported the endangered freshwater pearl mussel (*Margaritifera margaritifera*) population in the Kerry River, Scotland, declined 4-8% after the major flood of 1998, and that the mussel population may now be at greater risk from any subsequent catastrophic events.

For a critically endangered species like swamp deer taking this risk could prove to be fatal. Thus, it is hoped that management will take some mitigation measures to save this remnant population immediately, before the debacle occurs and this critical population is lost.

In nutshell, an equilibrium between flood (fluvial action) and maintenance of floodplain is vital, not only for the species like swamp deer but also for an array of floral and faunal species. Besides, floodplain is being used by local communities for farming and habitation in Dudhwa landscape. Undoubtedly, Jhadi *taal* is of prime importance for the long term conservation of swamp deer in the entire tract. All efforts at various levels are necessary for monitoring, maintenance, and management of this pivotal habitat.

Chapter 8

General Discussion and Conclusion

8.1 Human Disturbance and Landscape Change - Synthesis and Final Reflections

Forest ecosystems provide many things which people value over the years. The management objectives for forests have broadened to include maintenance of biological diversity (Oliver *et al*., 1999; Spies and Turner, 1999). Forest degradation is a worldwide phenomenon, particularly tropical forests in heavily populated developing countries (Bushmante *et al*., 2003). India, being a tropical and developing country is no exception. Human generally do not settle randomly on the landscape, rather human density and land use are often located to maximise access to critical resources (Hansen and Rotella, 1999). Land use patterns affect both terrestrial and aquatic systems and influence biodiversity (Reiners *et al*., 1994; Cooper, 1995, Pearson, 2002). Forests represent dynamic mosaics created by disturbance and biotic processes. Thus, forest landscapes are rich in spatial heterogeneity from a variety of causes, including environment, biotic interactions, disturbance, and succession. Resource managers are often unaware of the extent to which land use changes, disturbance, and biotic pressure affect spatial patterns and biodiversity in particular. Hence, the challenges facing natural resources managers increasingly occur over entire landscapes and involve spatial interdependencies among landscape components at many scales (Turner *et al*., 2002).

Theory and experience remind us again and again that world is tightly interconnected system where changes driven by humans can have far-reaching consequences across time and space (Marquet and Bradshaw, 2003). There is an increasing need to develop management and planning options both for landscapes that are already significantly altered and in need of either improved management or restoration and for landscapes which are still relatively unaltered but which are under increasing human pressure

(Hobbs and Lameback, 2002). The ability to provide such options depends on an understanding of landscape processes and the ability to use this understanding to develop appropriate strategies. The land use changes, habitat changes and forest fragmentation, and altered river dynamics in Dudhwa landscape represent the most direct effects of humans on this globally important landscape and have been shown to have a cascade of impacts on various integral components of complex, and dynamic *Terai* ecosystem (i.e. forest, grasslands, swamps, and rivers, and its floodplain) and distally in time and in space.

8.2 Dudhwa Landscape – A Remnant of *Terai* Ecosystem

'*Tharu*' tribals constitute the prominent and ancient section among the locals as they first inhabited the forest-grassland-swamp dominated landscape (De, 2001; Kumar *et al*., 2002). *Tharu* usually live very close to thick forest and a great number of *Tharu* villages are found in small clearings in the middle of the forest itself. They are settled cultivators and believe in traditional animistic religion. Till recent past, it seems that they lived in harmony with nature and forests as forest resources were wide spread and plenty, practised subsistence living, and remained unexposed to modern development. However, rapid transformation in their life style, needs, and interaction with outer world could be seen in past two decades or so.

Prior to the government control on most forests came in 1861, forests in Dudhwa landscape were under the control of Raja Khairigarh for the purpose of hunting reserves and commercial uses (Leete, 1902). The real importance of forest resources was recognized by 1870 by the than ruling British government as they laid massive rail and road network, developed other infrastructure – forest buildings, bridges, and facilities for mechanised forest working in subsequent decades. This was followed by heavy forest working, massive extraction of timber, and its export to other parts of the country and also outside and extensive clear-cuts and monoculture plantations for almost 7-8 decades. Simultaneously, a large number of people were also settled in the area by the Indian government during the post-independence period of the country and they were given land for agriculture. Expansion and Intensification of agriculture in otherwise once forest dominated landscape gave way to large number of other migrants (e.g. labourers) from other parts of the country. Sudden explosion in human population and agriculture expansion and intensification also resulted into the allied development in the area. This way, within a short span of >150 years all the components of *Terai* ecosystem – the forests, grasslands, swamps, rivers, and its floodplain have been severely occupied, influenced impaired and converted to human and agriculture dominated landscape with just three large and prominent, and several small widely scattered forest fragments as remnants of the original *Terai* ecosystem.

8.3 Land Use, Forest Fragments, and Conservation

Study amply revealed that three large forest fragments, presently as PAs (DNP, KWS, and KAT) not only harbour representative floral and faunal diversity of *Terai* ecosystem, but they together along with other small forest fragments constitute an important landscape for conservation of several native endangered faunal species including the flagship species i.e. tiger. This fact has also been supported by De (2001), Kumar *et al*. (2002), Johnsingh *et al*. (2004), and Jhala *et al*. (2008).

The assessment of land use/land cover patterns in Dudhwa landscape revealed an overall presence of 70.4% woodland represented by 44.8% Sal dominated forests, 18.8% other forests (Tropical Semi-Evergreen Forest, Tropical Seasonal Swamp Forest, Khair and Sissoo Forest, *Aegle* Forest, and *Terminalia alata* Forests) and 6.9% plantations. Besides the pre-dominance of nearly 3/4th woodland, grasslands and wetlands also occupied 18.0% and 7.0% area of the landscape (forestland), respectively. A comparison of land use/land cover patterns in three large forest fragments/PAs provided striking differences in distribution of several forest types and their area extent and these were appropriately highlighted in Chapter 3. Hence, each individual forest fragment is equally important so as to ensure long term persistence of specific vegetation types identified within them. Collectively, large and small forest fragments in all probability still harbour representative native forest diversity of *Terai* which might have existed prior to human occupation and enhanced disturbance. Nevertheless, three large fragments are in a significant altered condition as was evident by the presence of plantations of exotics (Teak and *Eucalyptus*) in wide spread small patches within each of the larger forest fragment. DNP was found as the most important fragment for long term conservation of typical Sal forests of the tract. The pre-ponderance of Open Sal Forests towards peripheral areas of three fragments calls for effective protection and management as they are under tremendous biotic pressure owing to large interface with peripheral villages and agriculture. The occurrence of highest proportion of Open Sal Forests in KWS and KAT among five Sal forests types can be attributed to the impact of past management. The threat to Moderately Dense Sal Forests and Dense Sal Forests, those are relatively located in interior locations also seems to be high owing to likely increased biotic pressure in the time to come. Possibility of these two forest types getting converted into Open Sal Forests in future can not be fully ruled out. In general, other forest types (e.g. Tropical Seasonal Swamp Forest) occurred in low extent in three fragments and that too in several small patches. Such forests in low extent and widely distributed patches not only require greater attention for their protection but also management interventions from their regeneration point of view.

Two types of grasslands i.e. the Upland and Lowland Grassland occurred in little more than 20% extent in DNP and KWS while the percentage coverage of two types of grassland in KAT was little more than over 10%. This peculiar variation in case of grasslands in KAT has already been attributed to the higher proportion of rivers and swamps. Interestingly, the overall ratio of Upland to Lowland Grassland in all three studied fragments was found almost similar, around 1:2.3. This is an important baseline information for the area and future monitoring and management efforts should ensure that the two types of grassland are maintained at least in the present ratio of 1:2.3 so as to facilitate conservation of several obligate species to these grasslands.

The network of rivers, rivulets, streams, and swamps is a characteristics feature of *Terai* and also vital for the maintenance of considerable terrestrial and aquatic life forms. The overall proportion extent of rivers, swamps, and sand bars was maximum in KAT as compared to KWS and DNP. The minimum extent was in DNP. The ratio of extent of rivers and swamps varied from 1.05 to 7.25. The lowest ratio was in case of DNP while rivers were much more pronounced in KAT than swamps. The situation in KWS was intermediate more or less similar to DNP.

The present study also highlighted the application of high resolution satellite data for land use/land cover mapping and development of a spatial database and specifically proved its relevance in the context of Dudhwa landscape.

8.4 Forest Vegetation

Study highlighted comparable plant diversity among forest fragments and also with other Sal dominated tropical forests. The long phase of 'active forest management' followed by a short phase (2-3 decades) of 'passive management' have definitely affected the structure and composition of forest vegetation in Dudhwa landscape. Introduction of exotics (Teak and *Eucalyptus*) and their successful establishment, loss of old growth forests, plantation in 'grassy blanks', spread of weeds (e.g. *Lantana camara, Parthenium* sp.) and preponderance of undesirable woody climbers – *Tiliacora acuminata* in Dense Sal Forests are some of the major reflections of past active and recent passive forest management. Nevertheless, it is worth mentioning here that in spite the phase of passive management is currently on, there is bonafide as well as illegal extraction of forest vegetation/resources by *Tharu* tribals and also enhanced biotic pressure on the peripheral areas. The impact of active forest management was probably more pronounced in KAT as compared to DNP and KWS. The extent of plant diversity in KAT was more close to two managed forests (NKFD and SKFD). Present study amply illustrated that the regeneration in case of native tree species and principal associate of Sal i.e. *Terminalia alata* was poor while the exotic Teak showed good regeneration and recruitment. This itself is a cause of concern

8.5 Forest Fragmentation and Effect of Matrix

Undoubtedly, the Dudhwa landscape has severely suffered not only on the account of habitat loss and habitat destruction but also due to forest fragmentation. In a vast landscape (8,093.3 sq km), the semi-natural forests which exist today occupy little over 2,000 sq km, that too in three large, disjunct and several small scattered fragments. Small, isolated forest fragments of NKFD and SKFD are obviously more prone to encroachment and degradation as they are embedded in matrix. The connectivity among three large fragments (PAs) is almost lost. The forest fragmentation in Dudhwa landscape in terms of simultaneous reduction of forest area, increase in forest edge, and sub division of large forest areas into smaller non-continuous forests as described by Laurance (2000) was much more evident due to changes in land use and other disturbances those occurred during recent decades. The present study provided baseline information on spatial heterogeneity in three large fragments. The use of FRAGSTATS and understanding of various forest class level metrics gave much desired insight on the process of fragmentation. Accordingly, among three forest fragments, forests of DNP were less fragmented. Also the habitat quality of various forests in DNP was found to be better than in KAT as indexed by mean core area and edge density. Interestingly, less fragmented forest patches in DNP were found far apart from each other affecting connectivity among patches of similar habitat type. Study notably documented that diverse forests in large fragments were found in their natural state as indicated by mean shape index despite active management for a long period, disturbance, and other biotic pressure. Counter-intuitively, patches of Teak plantations were also found of irregular shape indicating that those plantations of exotic species are fully established in the area. Findings in case of KAT specifically indicated the fragmentation of one large patch of Sal forest into several smaller patches as shown by metrics of mean nearest neighbour.

The highly human modified agriculture system makes the matrix in case of Dudhwa landscape. Lindenmayer and Franklin (2002) described four critical roles the matrix plays that relate to biodiversity conservation. Current conditions in the matrix of Dudhwa landscape seem to be highly negative to four roles as the matrix is now hardly able to support populations of species. Until one decade ago, wild herbivores (chital, wild pig, nilgai, hog deer, and swamp deer) used to venture outside DNP in adjacent agriculture fields for foraging and even seasonal dispersal to a few remnant traditional rutting grounds in case of swamp deer. Tiger also used to follow these wild herbivores and, therefore creating several management problems related to cattle predation, human injuries, and even occasional human killings (De, 2001). The Uttar Pradesh Forest Department has therefore created a unit called 'Tiger Watch' 22-25 years ago for patrolling and monitoring of wild herbivores/carnivores in adjacent agricultural fields (matrix). Now there is no 'Tiger Watch' unit as it was disbanded few years ago and moreover not many reports of crop damage and human injuries/killing from the matrix area are being reported. One thing is certain that populations of most wild herbivores have declined against what they used to be two decades ago and they are prone to poaching once they venture outside PAs into agriculture areas. Conditions in matrix instead of regulating the movement of organisms now largely prohibit such movement. Matrix is expected to buffer sensitive areas and reserves, but in case of Dudhwa landscape this function is now hardly played. Matrix is supposed to facilitate the maintenance of the integrity of aquatic systems. However, in the present context, matrix is hardly able to play even this critical role as people in matrix have started exploiting ground water for multiple crops in a year which is likely to affect peripheral swamps in adjacnt large fragments and also heavy use of pesticides, weedicides, and fertilizers in matrix ultimately affects water quality. A smaller matrix is being created within each large fragment as a result of agriculture expansion by *Tharu* and other villages as being encouraged by the present government policies. The effect of the matrix on remnant fragments has received the majority of attention in forest fragmentation research (Bushmante *et al*., 2003). However, not only in the case of Dudhwa landscape but also elsewhere in the context of other PAs/landscapes within the country, there is hardly any sign of realizing the importance of matrix and its likely effects on spatial patterns within forest fragments.

8.6 River Dynamics and Floodplain

The importance of fluvial process in the maintenance of ecological integrity of *Terai* ecosystem has been appropriately highlighted in Chapters 1 and 7. Present study was the first attempt to assess river dynamics in the context of Dudhwa landscape. Sharda River influencing the greater part of Dudhwa landscape showed increased instability with its west bank line to be more unstable. The period of 1990-99 was found the most influential for altered river dynamics. The increasing instability in recent decades has also threatened one of the prime habitats (Jhai *taal*) of endangered swamp deer in KWS. The Locational Probability Model developed in the present study supported the argument of threat to Jhadi *taal* by sudden inundation or choking of swamp by heavy siltation in the near future. Sharda River also depicted enhanced flooding and silt deposit. Floodplain was found encroached and pronounced conversion to agriculture was noticed. Personal observations, available documentation, and interaction with local people and forest staff distinctly revealed similar altered dynamics of almost all rivers and rivulets in the landscape. Forest/PA management has already encountered the significant problems arising due to the displacement of channel and also due to heavy siltation in case of Dhonda River, close to Gauriphanta in DNP. Dying of Sal trees and their replacement by *Syzgium cumini* was an end result. Likewise, Suheli River forming the southern boundry of DNP and influencing its prime wildlife habitats (e.g. Sathiana, Kakraha) was also found impacted by recent enhanced flooding and heavy siltation. Hence, the Forest Department availed assistance from an NGO to dredge silt adjacent to Dudhwa complex. By and large, the important role of rivers as ‘Sentinels’ or in the maintenance of ‘flood pulse’ or ‘circulatory system’ or overall health of the complex system have been overlooked and both, the scientific community and resource managers have neglected the quantification of channel changes, and their effect so as to plan mitigation strategies. The ecological integrity of the landscape and agriculture boom in the tract would continue until rivers, rivulets, and streams continue to perform much desired fluvial function.

8.7 Knowledge Gaps and Future Direction

The Dudhwa landscape is definitely highly complex and dynamic in nature in comparison to several other landscapes/regions within the country. It has already been significantly altered and needs restoration in many instances. Further, the landscape is experiencing all round rapid development and with current pace of development and biotic pressure is expected to change further beyond imagination. During the phase of forest working, a good amount of information on forest vegetation and standing forest crop used to be collected in three large fragments. Once these areas were carved out as PAs, the collection of much desired valuable information has been discontinued. The information on any aspect of landscape is now primarily available through occasional scientific researches carried out in the area. The extent and scope of majority past researches was rudimentary, theme specific and most of them are now outdated and need updation. Moreover, the management system is probably based on false assumptions that: (a) system is closed to outside influence and therefore management can ignore changes outside reserve boundaries; (b) system is self-regulatory, will remain relatively stable in the face of environmental change, and therefore management can rely on benign neglect; (c) system possess a single end point at which they are at equilibrium and therefore a management strategy of benign neglect will allow to maintain stability or return to the same compositional and functional state they were at in the past; (d) succession always proceeds through the same pathway so temporal changes are predictable and will take care of themselves; (e) disturbance is something that is outside the system so management can ignore it or try to stop if it occurs; and (f) humans are not components of ecosystem, so past impacts and their current actions can be ignored (Pickett and Ostfeld, 1995).

In time to come, rapid land use changes are expected in Dudhwa landscape and they would result into severly altered current matrix, further fragmentation, and much more degraded state of rivers, rivulets, streams, and swamps. This urgently calls resource managers, scientific community, NGO's and local communities to come together for participatory research and action oriented management interventions. Also they need to adopt a paradigm shift in view of above false assumptions or ignorance and practise an adaptive as well as landscape management approach to conservation.

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