CSD Working Paper Series – 011

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2003

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Effects of Forest Resource Extraction on Biodiversity Conservation Values: Towards a Sustainable Forest Management Strategy in Sariska Tiger Reserve, Rajasthan*

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Executive Summary

Sariska Tiger Reserve, located in the state of Rajasthan, is one of the most important areas for conservation of the endangered Royal Bengal Tiger in the region, representing the western-most limit of its range in northern India. Sariska, as many other sites in the Aravallis, is facing heavy pressure from forest biomass extraction from people who are dependent on the resources of the forest for their survival. Observations indicate that human use may be causing widespread and in some cases, severe, degradation of ecosystems inside the Reserve. Despite the fact

* The project would have been incomplete and perhaps impossible, without the participation of Mr. Mangu Singh who works as a nature guide in Sariska Tiger Reserve. The authors are grateful to him for his dedication, hard work and good cheer. This work was made possible by financial assistance from Center for Wildlife Studies, Bangalore; Wildlife Conservation Society-India Program and Wildlife Protection Society of India, New Delhi. The authors thank Mr. Tejbir Singh (Field Director, Project Tiger, Sariska Tiger Reserve) for his assistance during field work. The authors are also grateful to Mr. R.C. Soni (Principal Chief Conservator of Forests, Rajasthan) and Mr. Arun Sen (Chief Wildlife Warden, Rajasthan) for permission to work inside Sariska Tiger Reserve during this study. Mr Daulat Singh (Range Officer), Mr. B.M. Sharma (ACF) , Mr. Uday Ram (Range Officer) and Mr. Saini (ACF) in Sariska were also very helpful on the field. The authors are also very grateful to Mr. Jawed Ashraf, Mr. Ranjit Lal and Ms. Pratibha Pande, who took many of the photographs that were used in this report and to Ms. Jaya Nair for her efficient help in data analysis and report preparation. We are also grateful to Mr. Zain Khan for producing an excellent map of Sariska.

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that the forests of the Reserve are being exploited for forest products, there has been little serious evaluation of the accompanying ecological impacts or long-term biological sustainability of the prevalent extraction practices. Such evaluations are necessary to formulate viable long-term forest management strategies in the Reserve.

A study was carried out in Sariska Tiger Reserve to study the effects of intensive human use of forests on biodiversity conservation values using bird species and communities as indicators. Bird densities were estimated using fixed-width point transect sampling from March through May, 2003.

Substantial impact of small-scale habitat disturbance caused by intensive human use was seen on bird communities of dry deciduous and scrub forests of Sariska Tiger Reserve. Though species richness, species diversity and densities of birds were unchanged in disturbed areas, there were statistically significant differences in species composition between disturbed and undisturbed forest habitat. Graminivorous (seed-eating) birds were more abundant while insectivore-nectarivores (insect- and nectar-feeding birds) were less abundant in disturbed habitat in comparison to undisturbed habitat. In certain habitat types, frugivores and frugivore-graminivores were adversely affected by habitat disturbance while omnivores were encouraged. Bird communities of date palm-dominated riparian forest and mixed forests were more affected by habitat degradation than those of scrub forest and Anogeissus-dominated forest. The changes in bird community composition were mainly related to differences in canopy cover and in indices related to human disturbance such as lopping and weed density. Further collection of data on bird distributions is likely to reveal stronger effects of disturbance, as sufficient data on naturally rare and cryptic species could not be collected.

Since bird species have been found to be central to plant regeneration and therefore, to maintaining diversity of tropical forests, it is likely that loss of bird species may lead to a spiraling loss of overall biodiversity in the future. Further habitat degradation due to these reasons, poses a threat to the survival of the tiger in Sariska, one of only two Tiger Reserves in Rajasthan. We suggest that urgent action be taken to stop further degradation of habitat due to biomass collection and grazing in Sariska Tiger Reserve by finding viable alternatives for people living within the Reserve boundaries who depend on these plant resources.

Introduction

Sariska Tiger Reserve and biodiversity in the Aravallis

Sariska Tiger Reserve, located in the state of Rajasthan, is one of the most important areas for conservation of the endangered Royal Bengal Tiger in the region, representing the western-most limit of its range in northern India. Covering an area of 866 sq. km, Sariska represents the few remnants of native forest in the eco-region of the Aravalli Hills that are relatively better protected from human pressures in this region. Sariska harbours a diversity of flora and fauna that are characteristic of the scrub and dry deciduous forest ecosystem of the Aravallis including rare and endangered mammals such as the caracal, fishing cat, ratel and four-horned antelope (Rodgers, 1990; Government of Rajasthan, 2002). Sariska is extremely rich in avifauna with 225 species recorded so far and has been identified as one of the Important Bird Areas (IBA) in the state of Rajasthan by the Bombay Natural History Society (Bombay Natural History Society, 2001).

Sariska Tiger Reserve, as many other sites in the Aravallis, is facing heavy pressure from forest biomass extraction. Sariska has a large number of people who are dependent on the resources of the forest for their survival. There exist eleven small villages inside the core zone of the Reserve while another sixteen are located in the buffer zone (Government of Rajasthan, 2002). Most of the people of these villages depend almost completely on the resources of the forest for grazing, fuelwood collection, fodder collection as well as extraction of many food and medicinal plant species. There is therefore a high degree of human use of forests in some parts of the Reserve. Observations indicate that human use may be causing widespread and in some cases, severe, degradation of ecosystems inside the Reserve.

Despite the fact that the forests of the Reserve are being exploited for forest products, there has been little serious evaluation of the accompanying ecological impacts or long-term biological sustainability of the prevalent extraction practices. It has generally been assumed that produce extraction from forests is sustainable in the long term and that it can have little or no adverse impact upon their biodiversity conservation values. However, it has been found in other areas that certain kinds of forest use can become ecologically unsustainable due to intensification of extraction pressures and changing demands from forests (Murali *et al.*, 1996; Shankar *et al.*, 1998).

The sustained use of forests for produce collection and grazing can lead to reduction in tree regeneration, canopy cover, understorey diversity and the structural heterogeneity over a period of time (Shankar *et al.,* 1998). Such changes are often followed by the invasion of exotic plants and changes in microclimatic and soil conditions, as seen in many places. Importantly, changes in forest structure and plant composition are likely to impinge upon the existence of native animal species. Groups of animals that are especially vulnerable to population declines in such areas are fruit-feeding birds and mammals that depend on a diversity of plants, bird species that are selective in their habitat preferences and insect species that depend on specific microhabitats for foraging or breeding activities. The gradual loss of insect, bird and mammalian species that serve as pollinators and seed dispersers, is likely to affect future regeneration and productivity of plants and thus lead to spiraling ecosystem degradation and species impoverishment in the long term (see Terborgh, 1998). Further ecosystem degradation in Sariska is thus likely to lead to extinction of the endangered Royal Bengal Tiger in one of its critical habitats in northern India.

In view of growing pressures on forests in Sariska, there is an urgent need for evaluation of the indirect ecological impacts of forest use that can inform future management strategies. The present study aims to evaluate the indirect ecological impacts of forest use inside the Reserve through a comparative study of biodiversity conservation values between areas facing high and those facing relatively low extraction pressure, using bird species as indicators.

In an era of escalating demands on the natural resource base of Indian forests, there is a growing need to define sustainability in concrete terms rather than continue to view it as a diffuse objective. Quantitative knowledge of human impacts can enable formulation and implementation of suitable management measures that may be necessary to stall this decline.

Birds as indicators of human disturbance and land-use change

Birds have been found to be excellent indicators of forest structure and function, and therefore, of degree of habitat disturbance. The diversity (ie, numbers of species and their distribution across abundance categories) and species composition (numbers of various species) of bird communities is closely related to the level of human impact in forest habitats. This relationship has been studied through evaluating the effects of various forest management and extraction practices on the structure and composition of forest bird communities (for example see Duguay *et al.*, 2001; Gabbe *et al.*, 2002; Lohr *et al.*, 2002).

Studies indicate that the drastic simplification of habitat from a multi-storeyed, multi-species forest to a single-layered and species-poor vegetation layer causes impoverishment of bird communities and drastic changes in bird species composition (Thiollay, 1999; Duguay *et al.*, 2001). Such simplification of habitat occurs during a variety of forest uses such as clear-felling, selective logging, conversion of forests to plantations, intensive biomass collection or agriculture. In a study in Uganda, it was found that there was moderate overlap of bird species between logged forest and unlogged primary forest (Dranzoa, 1998). However, there were some forest interior species that did not reappear in the logged forest even 23 years after recovery (Dranzoa, 1998). In south-east Asia, diversity of forest-dwelling bird species was found to undergo reduction after selective timber harvest (Johns, 1986, 1987, 1989; Thiollay, 1997) although several species were able to survive the transformation of habitat. In all cases, the extent of unlogged buffers in and around the logged areas seemed to play an important role in determining the local abundance of various bird species (Johns, 1986, 1987). One consequence of reduced species richness of trees in managed forests is the increase in phenological gaps (ie, the periods when no fruit or nectar resource is available for a particular bird group) which results in fewer bird species being able to survive in a habitat throughout the year.

Studies in monocultural plantations show that composition of bird communities is affected by the homogenization of tree diversity, simplification of vegetation structure and reduction in canopy cover, necessitated by the conversion of native forests into plantations. A number of studies have been carried out in coffee plantations in India and Central America (Borrero, 1986; Wunderle and Waide, 1993; Wunderle and Latta, 1994; Shahabuddin, 1997). In more monospecific and heavily trimmed coffee plantations, populations of frugivores, bark-gleaners and understorey species were reduced (Greenberg *et al*, 1997). Greenberg *et al.*, (1997) also found depauperate bird communities in coffee plantations as compared to natural habitat patches. Specialised forest species were absent from coffee plantations while edge and second-growth species were most common. Other types of plantations such as those of eucalyptus have been found to be extremely depauperate in bird species in comparison to native forest (Marsden *et al.,* 2001).

Shifting cultivation is a form of agriculture that is widespread in north-eastern India and south-east Asia and is generally carried out by clearing secondary or pristine forest. Such areas are left to regenerate after cultivation for a year or two. The value of such shifting cultivation areas for birdlife is very low immediately but tends to improve with the number of years after abandonment (Raman, 1998) carried out a pioneering study of recovery of bird communities in shifting cultivation patches in Mizoram in various stages of vegetation succession. He found that though similarity of bird communities of abandoned patches with those of natural undisturbed forest slowly increased with time after abandonment, yet there were some rainforest specialist bird species that did not reappear even after a hundred years after abandonment of shifting cultivation plots. Similar results have been obtained in studies carried out in shifting cultivation plots in other tropical areas (Bowman *et al.*, 1990; Blankespoor, 1991; Andrade and Rubio-Torgler, 1994).

The reasons underlying habitat selection in birds have been investigated in a number of studies carried out since MacArthur's pioneering study on the correlation between the structural complexity of vegetation and bird community structure (MacArthur and MacArthur, 1961). The important habitat features to which bird species have been reported to respond are: vertical heterogeneity of vegetation, understorey density, vertical foliage distribution, canopy height and density and species composition of tree species (Hanson *et al*, 1991; Canterbury *et al.*, 2000; Lindenmayer *et al.*, 2000; Poulsen, 2000; Brawn *et al*, 2001; Suter *et al*, 2002; and Raman, 2002,). Deferrari *et al.*, 2001 found that plant biomass and insect abundance were two of the important habitat features that determined local bird abundance. Bird species also respond to specific structural features of forest. Height of canopy and density of large trees may be important variables to which larger bird species such as hornbills or raptors respond (Datta, 1998). Dale *et al.*, (2000) found a close relationship between the composition of understorey bird communities and forest edge in Uganda. Lohr *et al.*, (2002) found significant effects of removal of standing dead trees (snags) and fallen wood on bird communities in pine forest in north

America including species such as woodpeckers, wrens and songbirds. This study has significant implications for management of Indian forests where collection of deadwood for fuel is widespread and intensive in many areas.

Bird species are also known to exhibit some degree of selection with respect to tree species. Gabbe *et al.*, (2002) found that twelve of thirteen foliage-gleaning bird species were selective in their choice of tree species to forage in. Raman, (2001, 2002) and Poulsen, (2002) also reported sensitivity of forest bird species to vegetation species composition in managed and unmanaged forests.

Connectivity and heterogeneity of forest ecosystems at the landscape level are other features that may determine the characteristics of bird communities at a particular spot (Lindenmayer *et al.*, 2000). Increasingly, ornithologists are taking into account landscape-level habitat features, rather than simply local habitat features, in their studies of bird communities (see Natuhara and Imai, 1999).

Objectives

Specifically, the objectives of the proposed study are to:

(1) quantitatively evaluate the effect of intensive forest use (for grazing and biomass extraction) on the avifauna of Sariska Tiger Reserve in Rajasthan;

(2) to assess the changes in vegetational characteristics that may account for the observed impacts of forest use on birds, and

(3) to recommend management strategies for forest conservation based on the results of the study.

Study site

Sariska Tiger Reserve covers an area of 866 sq.km. in Alwar district located in northeastern Rajasthan. The Reserve is composed of the notified Sariska Wildlife Sanctuary, covering 492 sq.km. and adjoining Reserved and Protected Forests which together cover 374 sq.km (see Figure 1). Core Area I of the notified WLS has been proposed for National Park status (Government of Rajasthan, 2002; see Figure 1)

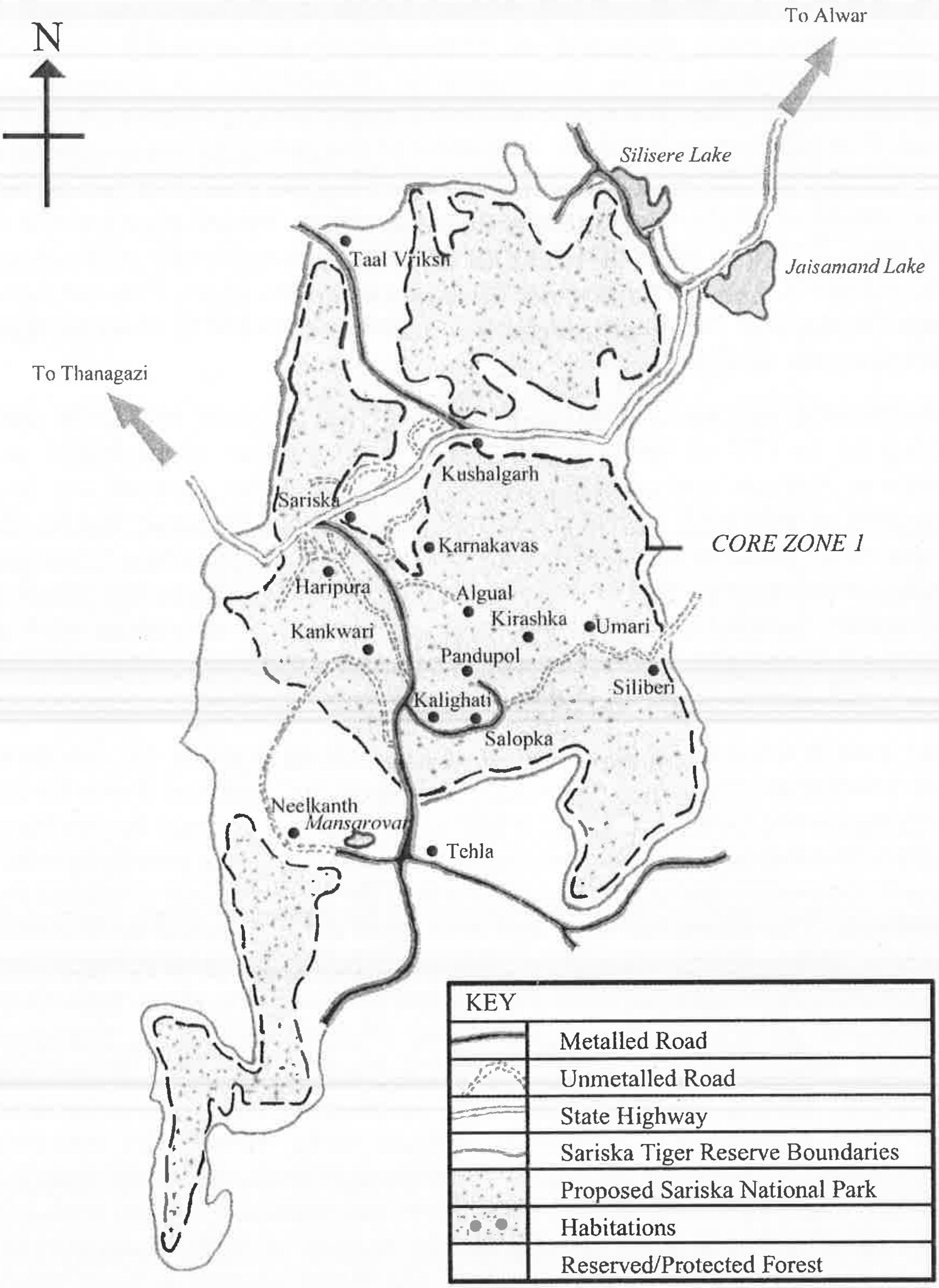

Figure 1 : Map of Sariska Tiger Reserve

The Reserve is located in the Aravalli range in the semi-arid zone of north-western India delineated as biogeographic province 4A (semi-arid Gujarat-Rajputana) in the biogeographic classification of Rodgers and Panwar (2002). The area is seasonally dry, experiencing an average annual rainfall of 650 mm per annum with most of the precipitation occurring in the months of July, August and September. Thus the area does not receive any rainfall at all (or very insignificant amounts) for almost nine months of the year. The area experiences extremes of temperature with cold winters (November to February) and extremely hot summers (April through June) with the daytime maximum temperature going up to 50° C in some years (Government of Rajasthan, 2002).

The Reserve has an undulating terrain with valleys, hills and rocky cliffs going up to 700 m (asl), dotted with a large number of perennial and seasonal springs and streams. While perennial water sources are few, seasonal ponds and streams occur throughout the Reserve during the monsoons. Most of the valley areas also have high sub-surface water and underground springs that emerge as streams. There are three big plateaus, Kankwari, Sariska and Kirashka, and numerous narrow valleys such as Kalighati, Pandupol, Bandipul, Algual and Raika. The hills extend mainly in a north-east to south-west direction across the Reserve.

The area is covered by forests formally known as tropical dry forests of two categories: tropical dry deciduous forests and tropical thorn forests (Champion and Seth, 1968). Low hills and slopes are covered by deciduous forests dominated by *Anogeissus latifolia* and *Anogeissus pendula*, mixed in with *Boswellia serrata*, *Lannea coromandelica*, *Wrightia tinctoria* and bamboos. The ridges, hill-tops and drier strata are dominated by *Boswellia serrata*. Valley bottoms having a high water table, seasonal streams and/ or perennial springs have taller and thicker forest having *Ficus infectoria, Mitragyna parvifolia, Ficus glomerata, Phoenix sylvestris, Syzygium cumini, Diospyros melanoxylon, Mangifera indica and Terminalia bellerica,* among other species. Such forest growing in moist localities can reach heights of 12-15 m. In narrow rocky valleys with perennial water sources, *Phoenix sylvestris* is commoner than the other associate species. Date palm-dominated vegetation also occurs in places with very high water tables such as the plateau-like regions of Umri, Kankwari and Kirashka (see map: Figure 1). In drier and flatter terrain such as alluvial valleys and plateau areas, tropical thorn forests dominate and consist of

Zizyphus mauritiana, Acacia leucophloea, Butea monosperma, Balanites aegyptiaca, Acacia catechu and Aegle marmelos. The understorey of scrub forests consists of *Capparis sepiaria, Capparis decidua, Zizyphus mummularia and Adhatoda vasica.* Grasses such as *Cenchrus ciliaris, Dicanthium annulatum and Heteropogon contortus* occur in the scrub forest and other flatter terrain. A number of invasive species have become common in the intensively used areas of the Reserve such as *Cassia tora* and *Prosopis juliflora.* Currently, a few plants of the exotic weed *Lantana camara* have been seen in the outskirts of the Reserve. *Adhatoda vasica,* though a native understorey species, has become very common in disturbed areas, and appears to suppress grass and other herbaceous species.

The eleven villages inside the Core Zone of the proposed National Park (see Figure 1) are inhabited by approximately 860 families, mostly belonging to the Gujjar community (Government of Rajasthan, 2002). Most of the resident people are livestock graziers by profession and possess goats, sheep, camel, buffaloes and cows. Their only source of income is the production of milk, which they sell outside Sariska. The local people collect leaves from trees and shrubs for stall-feeding and sometimes graze their livestock, going long distances each day in search of fodder, sometimes as far as 10-15 km. In addition, the people meet all of their fuelwood requirements through collection of deadwood from the forests within the boundaries of the Reserve.

Methods

The basic approach in our study was the comparison of the structure and composition of bird communities of forest areas facing high pressure of human use in the form of grazing, fodder collection and fuelwood collection with those of areas that are relatively better-protected and that face little or no pressure from such activities.

Identification of sites

Through intensive exploration of the Reserve, observations, and interviews with village people, tourist guides and forest department staff, areas facing high and those facing relatively low human pressure, were identified within the Reserve. Areas facing intensive human use (henceforth referred to as '*disturbed sites*') were mostly located close to some of villages within the Core Zone I of the Reserve such as Umri, Kankwari and Haripura, where human use is most intense. The areas with relatively low pressure from grazing and fuelwood collection were Salopka, Bhaironghati, Kalighati and Governor's Route (henceforth referred to as *'undisturbed sites'* in this report. Status of disturbance levels was monitored subsequently during the course of the study and largely bore out the assumptions of human disturbance levels that formed the basis for site selection (see section on Vegetation Characteristics). These observations were based on actual observations of human activity in the area including grazing of livestock and fodder collection, abundance of weeds and evidence of lopping of trees.

Forty sites were marked in the Reserve, twenty in disturbed habitat and twenty in undisturbed habitat. Within each of the disturbed and undisturbed habitat categories, four most widespread vegetation categories were represented, each by five replicates (see Table 1 for sampling scheme adopted for the study). The four major vegetation types identified for our purposes were scrub forest (occurring on flat/plateau terrain), date-palm-dominated riparian vegetation, slope forest dominated by *Anogeissus spp.* and miscellaneous forest (such as those growing on ridge-tops and along streams). For convenience, these four habitat types will henceforth be referred to as 'date palm forest', 'scrub forest', 'mixed forest' and *'Anogeissus forest'*. Sites were separated by a distance of at least 200 m from each other.

Bird observations

Fixed-width point transects of 40 m radius were used for collecting data on birds. Fixed-width point transects have been recommended for collection of data on bird communities in areas with heterogeneous fine-grained habitats, where large amounts of data are to be collected over a short period of time and where sufficient sample sizes are required for statistical analysis (Bibby *et al.*, 1992; Raman, 2003). Further, data collected using fixed-width transects have been found to be highly correlated with data collected using variable-width transects from the same habitat although density estimates utilizing fixed-width transects have been found to be generally lower than those obtained using variable-width transects. However, in a comparative study of bird densities across habitat categories, such differences are not likely to affect results.

Each of the forty point transects were covered five times for sampling during the period of the study on a rotational basis. At each selected site, birds were recorded for fifteen minutes on a given sampling day. At each site, birds spotted within a 40-m radius of the given point/site were identified and recorded. Calling birds were not recorded unless it could be ascertained that they were calling from within the 40-m radius. Birds were identified using Ali and Ripley, (1983) and Grimmett *et al.*, (1998). However, nomenclature follows Grimmett *et al.*, (1998). In addition, detailed notes were made on the breeding and foraging activities of birds during each point count, specially with reference to the tree/shrub species on whose flowers or fruits the bird was seen feeding on. Birds observed to be flying over the area of the point transect or soaring overhead were not recorded. However, flying birds were recorded if they were flushed out from within the area of the point transect by the observer or observed to be flying into or out of the transect area during the fifteen-minute duration of the count.

Counts were started half-an-hour after sunrise and continued for 3 hours after that, approximately between 7 A.M. and 10 A.M., each morning. Bird observations were made during the peak breeding season between March 9 and June 4, 2003.

Vegetational characteristics

Within the 20-m radius of the central point of each point transect, all trees having a girth of 30 cm or above were identified and counted. Woody plants (ie, shrubs and saplings) greater than 1 m in height but having a gbh of less than 30 cm were also exhaustively counted and identified within the 20-m radius of the central tree of each point transect.

Vegetational structure was quantified using two indices: extent of canopy cover and foliage height diversity. Extent of canopy cover was quantified using a circular eyepiece. At each point transect, one of the 40-m diameter lines was chosen randomly. The observer, walked along this diameter line, looking up at the canopy every 2 m through a cardboard tube 2" in diameter. If more than 50% of the viewing area of the tube was covered by foliage, a '1' was recorded while if less than 50% was covered by foliage, a '0' was recorded. The canopy cover for a particular transect was calculated as the total number of '1's along that 40-m diameter line and thus ranged from 0 to 20. To quantify vegetational structure, using the same points along the chosen diameter line as used for canopy cover observations, presence or absence of foliage was noted as 0, if absent and 1, if present, within each of three height categories 0-2 m, 2-6 m and >6 m. Foliage height diversity (FHD) was then calculated as $\Sigma Pi^* \log(Pi)$ where p_i refers to the proportion of foliage seen in a given height category.

Indicators of habitat disturbance were additionally recorded in terms of proportion of trees lopped by people and frequency of human use. At each point transect, the number of trees showing signs of lopping by humans, was recorded at each transect. From this number, the percentage of trees showing signs of lopping was quantified. During each of the five visits to each site, signs of human use such as grazing livestock, people seen collecting plant material and presence of cattle/goat dung were noted. Disturbance was quantified on an ordinal scale as the number of times out of five visits, that any such signs were seen and thus ranged from 0 to 5. Weed density was calculated as the number of plants of *Adhatoda vasica* that were counted within each point transect. This was the only weedy species seen inside the transects.

Results

Bird community

A total of 149 species of birds were observed during the course of the study, of which 78 species were recorded during point transects while 71 were seen only outside of transect counts. The latter category includes species that naturally occur at low densities such as brown fish owl and grey hornbill and possible passage migrants such as the blue-tailed bee-eater and little pied flycatcher. A complete list of bird species recorded during the study is given in Table 2. Bird names follow Grimmett and Inskipp, (1998).

There are indications that the species-effort curves for most sites are tending towards saturation, implying that birds have been exhaustively covered in the study transects, at least for the season that was covered (Figures 2a to 2d). However, considerable change in species composition of birds has been observed in Sariska during monsoon, which is likely to continue with passage and winter migrations (pers. obs.). Therefore, it is likely that the species-effort curves for some or all of the study sites may slope upwards again if further observations are made during the monsoon and winter.

Bird density

Bird density at a given transect was calculated as the cumulative number of individual birds of each species that were seen at a given site over all five sampling days. Bird densities were not significantly different between disturbed and undisturbed sites according to a Kruskal-Wallis test (Sokal and Rohlf, 1981; $X^2 = 1.26$, $p < 0.2615$; Figure 3a). Kruskal-Wallis test is the non-parametric equivalent of an analysis of variance test that is used to test for quantitative differences between one or more groups (Sokal and Rohlf, 1981).

Bird species richness

Bird species richness was calculated as the cumulative number of bird species seen in a site over all sampling days. Kruskal-Wallis test revealed that there was no significant difference between the bird species richness of disturbed and undisturbed sites ($X^2 = 0.3741$, $p < 0.3741$; Figure 3b).

Bird diversity

Bird diversity was estimated for each site using two indices, the Shannon-Weiner Diversity Index and the Simpson's Diversity Index (Magurran, 1988). Diversity indices take into account both number of species present in a given site, as well as their relative proportions in a community. More diverse communities exhibit greater evenness of abundance across species and harbour greater numbers of species. However, while the Shannon-Weiner index emphasizes the species richness component of a community, the Simpson's index emphasizes the degree of evenness across species (Magurran, 1988).

Neither of the two calculated indices showed significant differences between disturbed and undisturbed sites (Shannon-Weiner: $X^2=0.8243, p<0.3639$ and Simpson: $X^2=0.0885, p< 0.766$; Figure 3c and 3d).

Variable numbers of individuals that are seen at different sites can bias estimates of species richness. For example, if one sees fewer individuals at a site, it is probable that fewer species will be seen as well. Thus in some cases, gross species richness may not be a good indicator of community structure. In order to find out whether there were any significant differences in species richness, taking into account net numbers of individuals observed at various sites, rarefaction analysis was carried out using the programme Ecosim (Gotelli and Entsminger, 2001). The analysis, using bird composition data from transect D26 where most individuals were seen, further confirmed that any difference in species richness between disturbed and undisturbed sites is unlikely. The rarefaction curve shows that most of the sites are located well above the 95% confidence intervals for species richness generated using 1000 randomizations (Figure 4). Figure 4 also indicates that disturbed sites have slightly higher species richness than undisturbed sites, than would be expected by chance.

Bird community composition

Species composition of a community indicates the identity of species and their relative abundances in the community. In this case, the identity of individuals becomes important rather than simply numbers of species. In order to study the variation in bird species composition across sites in the Reserve, Detrended Correspondence Analysis (DCA) was carried out with the bird abundance data ordered according to sites using PC-Ord package (Jongman *et al*, 1995; McCune and Mefford,1999). No down-weighting of rare species was done as it was felt that naturally rare species should be allowed to contribute as much to community differentiation as the more common species. DCA indicates weak differentiation of sites based on bird species composition. The first axis accounted for only 33.67 % of the variation in bird species composition and the second axis 11.34 %. Thus bird communities show weak differentiation across disturbance categories. As expected, sites within each of the four habitat types were clustered. However, there is distinct differentiation of bird communities between disturbed and undisturbed forest in the case of two of the four vegetation types: date-palm forest and mixed forest, indicating that disturbance strongly impacts the bird communities of such areas (Figure 5). Bird communities of scrub forest or *Anogeissus* forest, however, do not show much difference between disturbed and undisturbed sites.

Ordination gives only a qualitative picture of how different communities are and such differences cannot be quantified in any way. In order to explore quantitatively whether bird communities differ significantly between disturbed and undisturbed sites in terms of species composition, similarity analysis was carried out using three widely used similarity indices: Jaccard's index, Sorensen's index and Morisita-Horn index (Magurran, 1988; Colwell and Coddington, 1994; Colwell, 1997). While Jaccard's index takes into account only presence or absence of species in a given site, Sorensen's and Morisita-Horn indices take into account relative abundances of species as well (see Colwell, 1997 for definitions of indices). In order to find out whether disturbed sites were significantly different from undisturbed sites in terms of bird species composition, each of the 40 sites were compared with each of the others, by calculating inter-site similarities using the programme EstimateS (Colwell, 1997). This yielded 780 inter-site comparisons. Similarity indices calculated between pairs of disturbed or undisturbed sites were separated from the indices calculated between pairs of disturbed and undisturbed sites, thus giving two groups of similarity indices. These two groups of indices are referred to as 'within-group' (n=374) and 'across-group' (n=406) similarities, respectively. These two groups were than statistically compared using the Kruskal-Wallis test. This procedure was carried out for each of the three chosen similarity indices.

The results indicate that 'within-group' similarities were significantly greater than 'across-group' similarities, showing that disturbed and undisturbed sites differ significantly in terms of bird species composition. These results were consistent across all three similarity indices used (Jaccard: $X^2 = 13.37$, $p<0.0003$; Sorensen: $X^2=18.24$, $p<0.0001$; Morisita-Horn: $X^2=27$, $p<0.0001$; Figure 6).

Relative abundance of various feeding guilds

Feeding guilds of birds (or any other taxon) are groups of species that feed on similar resources in the ecosystem. For examples, birds that feed on insects from leaf litter on the forest floor, form a single feeding guild. Intensive habitat use or human disturbance is likely to affect the food resource base in a forest ecosystem and this may affect the structure of a community in terms of relative abundance of various feeding guilds. In order to study the effect of habitat use on various functional guilds of birds, the bird species recorded during transect counts were first classified into feeding guilds based on their food sources as reported in Ali (1996). The different categories of food sources that were mentioned in Ali (1996) and that were therefore, considered, were fruits, insects, carrion, smaller vertebrates, seeds, nectar and aquatic organisms. If a species was reported to be feeding primarily on one of the above food categories, it was assigned to one of the following guilds: frugivore (fruit-eating), insectivore (including bark-gleaning, sallying, understorey and canopy-feeding insectivores), graminivore (seed-eating), raptor (smaller vertebrates such as birds and reptiles), scavenger (carrion), nectarivore (nectar) or aquatic (wetland species). If a species was reported to be feeding principally on more than one category of food, it was assigned to one of the following combined feeding guilds: insectivore-raptor, insectivore-nectarivore, insectivore-frugivore, insectivore-graminivore and frugivore-graminivore. When a species was reported to be feeding equally on more than two categories of food, it was assigned to the omnivore category. The feeding guilds to which the bird species were assigned are given in Table 3. A total of fourteen feeding guilds were constituted of the 78 species of birds that were recorded during transect counts.

A series of chi-square tests for goodness of fit, were carried out to explore differences in relative proportions of various feeding guilds between disturbed and undisturbed habitats. Abundance of birds in various feeding guilds was found to differ significantly between disturbed and undisturbed habitats in all vegetation types and in all the forty sites taken as a whole (*Anogeissus* forest: $X^2 = 171.25$, df=10, $p<0.001$; date palm forest: $X^2=864.12$, df=10,$p<0.001$; mixed forest: $X^2=106.42$, df=10,$p<0.001$; scrub forest: $X^2=115.42$; df=9,$p<0.01$; combined habitats: $X^2=419.33$, df=12, $p<0.001$). Figures 7a to 7e show these results graphically.

These results indicate that the feeding guild composition of the bird community, differed significantly between disturbed and undisturbed habitats. Taking all habitats together, disturbance appears to reduce the insectivore-nectarivore guild and increase the guilds of omnivores and graminivores (Figure 7a). The same pattern is amplified in the date palm habitats (Figure 7d). Additionally, in this habitat, frugivore-graminivore and frugivore guild is highly reduced in disturbed habitat in comparison to undisturbed habitat. However, omnivores seem to be reduced by disturbance, rather than increased, in scrub forest and mixed forest. Thus ways in which some of the feeding guilds are affected by disturbance, vary across habitat types. The only pattern which is common to all four habitat types is the reduction in the insectivore-nectarivore guild and expansion of the graminivorous guild after disturbance.

Species-wise analysis

In order to study the effect of habitat disturbance on specific bird species, the abundance of each of the 78 species recorded during transect counts, was compared between disturbed and undisturbed habitats using Kruskal-Wallis tests. The results are given in Table 4. Out of 78 species recorded during the point counts, 9 species showed significantly higher abundance in disturbed forest in comparison to undisturbed forest (Table 4). These include species such as common myna, house crow, house sparrow, greater coucal, collared dove and Indian robin. Eleven species were significantly more abundant in undisturbed habitat such as common woodshrike, great tit, redvented bulbul, grey-crowned pygmy woodpecker, magpie-robin, tree-pie and white-eye. The remaining 59 species showed no significant differences between disturbed and undisturbed habitats. These include species that were spotted ten times or less during the entire set of transect counts.

Table 5 lists the species that were seen ten times or less during the course of the transect counts. Of these 31 species, 15 species were spotted only in disturbed habitats, including pied starling, Egyptian vulture and yellow-eyed babbler. However, 10 species were spotted only in undisturbed habitat including Indian nightjar, red-headed vulture, Tickell's blue flycatcher and Bonelli's eagle. Seven species, including the Asian koel, lesser whitethroat and white-throated kingfisher, were seen in both disturbed and undisturbed habitats.

Of the 70 species seen outside of transect counts, 41 were wetland species seen at a seasonal lake in the Kankwari village area and at Mansarovar, an artificial reservoir near the village of Tehla (Table 6). Apart from these wetland species, 30 species were seen in various categories of forest habitat of which 10 were restricted to undisturbed habitat. The latter category includes raptorial species such as the brown fish owl, Eurasian sparrow-hawk and insectivores such as little pied flycatcher, verditer flycatcher, grey nightjar and black-headed cuckoo-shrike. 17 were seen only in disturbed habitat.

Thus of a total of 149 bird species recorded during the course of the study, eleven were significantly affected by habitat disturbance, while twenty additional species are likely to be affected, given their presence and absence from various habitats.

Changes in vegetation characteristics

In terms of disturbance levels, all three disturbance indicators were measured to be significantly higher in disturbed sites in comparison to undisturbed sites (Figure 8a to 8c: frequency of human disturbance: $X^2= 18.85$, $p<0.0001$; density of weeds: $X^2 = 6.83$, $p <0.009$; % trees lopped: $X^2= 25.05$, $p<0.0001$).

Canopy cover was found to be significantly higher in undisturbed sites in comparison to disturbed sites (Figure 9e: $X^2 = 11.3262$, $p<0.0008$). However, foliage height diversity (FHD) was not found to be significantly different between disturbed and undisturbed sites, although mean FHD was higher in undisturbed sites than in disturbed sites (Figure 9f: $X^2 =0.279$, $p<0.5974$).

Undisturbed sites had higher tree density and tree species richness than disturbed sites. However, these differences were not statistically significant (Figures 9a and 9b; tree density: $X^2 = 1.11$, $p<0.2911$; tree species richness: $X^2=0.31$, $p<0.5758$).

Understorey density (including shrubs, saplings and weeds) was significantly higher in disturbed sites in comparison to undisturbed sites (Figure 9c;$X^2=4.23$, $p<0.0398$). The number of species in the understorey was also higher in disturbed sites, though this difference was not statistically significant (Figure 9d; $X^2=2.23$,$p<0.14$).

Relationships between bird species abundance and vegetation characteristics

In order to explore the relationship between abundance of bird species that were found to be affected by habitat disturbance and features related to vegetation, simple correlations were carried out between bird species densities and each of the eight vegetation features that were calculated for each transect. Table 8 shows the results of this analysis. The vegetation variables with which most of the bird species showed a significant positive correlation were canopy cover and tree species richness, including the great tit, magpie-robin and oriental white-eye. Percentage of lopped trees and human disturbance was also significantly negatively associated with densities of some of these species. Weed density, foliage height diversity and understorey richness were not correlated with any of the bird species densities. Thus loss of canopy cover and loss of tree species appear to be the two important habitat features related to intensive human use that cause decline in sensitive bird species.

Discussion

The study indicates that though species richness and diversity of bird species was not affected by habitat disturbance, there was a substantial difference between bird species composition of intensively used forest and those of relatively undisturbed areas inside the Reserve. 14% of forest bird species showed quantitative decline in densities in disturbed sites while 11% seemed to be encouraged by habitat degradation. Taken together, similarity analysis and comparison of the relative abundances of feeding guilds confirm that structure and composition of bird communities is significantly affected by intensive forest use. The findings of this study closely concur with numerous other studies on the effects of land use change on bird communities that have been undertaken in tropical areas (Johns, 1989; Pramod *et al.,* 1997; Raman *et al.,* 1998; Zakaria *et al.,* 2002).

The present study may be the first to examine the effects of chronic and intensive biomass collection on bird communities in a tropical forest. The study shows that the effects of long-term human use may be similar to those that are brought about by larger-scale and drastic land use change such as logging and conversion of forests to plantations (see Raman and Sukumar, 2002; Zakaria *et al.,* 2002; Craig, 2002). Such dependence on forests needs to be taken into account, if we are to sustainably manage forests for biodiversity conservation, particularly in national parks and wildlife sanctuaries.

The large number of samples in each category (ie, twenty), covering the entire range of habitats found within Sariska lend further credence to the findings of this study. Usually studies of human impact on biodiversity values are limited by lack of availability of comparable control sites, so that statistical analysis is not possible (Freese, 1997). In the present study, however, the availability of well-protected control sites in all habitat types, allowed viable comparisons between disturbed and undisturbed areas. Repeated sampling, made possible by the utilization of the point transect method, allowed sufficient sample sizes for some species, to be collected at each site. Further sampling is required, however, to verify the results obtained during this study, for ascertaining the status of species that were seen few times. Further comparable sampling is proposed to be carried out in the winter of 2003 to fill this lacuna.

Some bird species that appear vulnerable to local extinction in the face of continuing habitat degradation include common woodshrike, great tit, rufous treepie, magpie-robin, white-bellied drongo, white-eye and red-vented bulbul. Some of these species are often seen in scrublands and gardens in urban areas (even in dense metropolises in the same eco-region like Delhi; pers. obs.) and their decline in degraded areas of the Reserve point to the extreme levels of degradation in some parts of the Reserve. In addition, twenty-one other species appear likely to be affected by disturbance but they were seen too rarely or were seen outside of transect counts so that their densities could not be compared statistically between disturbed and undisturbed habitats. This group includes several bird species that were seen only in heavy forest cover and undisturbed habitat in riparian areas such as the Tickell's blue flycatcher and the brown fish owl. Several raptors were also seen rarely such as the Bonelli's eagle, Eurasian sparrowhawk and the steppe eagle but only in undisturbed habitat patches. Thus bird species that naturally occur at low densities, such as habitat-specialized, raptorial or passage-migratory species, may require observation over much longer time periods and larger spatial scales for a better understanding of their habitat preferences in relation to human disturbance.

We think that the above findings with respect to the impact of human disturbance on bird communities, may be conservative, for two reasons. First, as mentioned earlier, sufficient data could not be collected on as many as 102 species, that were seen either outside transect counts or fewer than ten times, due to the short-term nature of the project. From the presence-absence tables (Tables 5 and 6), one can infer that several other species are likely to show effects of disturbance. Second, the disturbed sites that were sampled during the study included both those located inside small 'disturbance patches' (< 100 m in diameter) as well as those located inside large patches such as are seen around villages, some of which extended for more than 5 km in diameter. In addition, the degree of degradation was not uniform across sites in the disturbed category, with certain disturbed sites being completely bereft of natural vegetation and others showing less intense disturbance. Generally, smaller disturbance patches were also less disturbed (pers. obs.). It is likely that confining sampling to large-scale disturbances and to highly degraded areas, would have considerably amplified the observed effects on bird communities. Though some bird species are strictly habitat-restricted, other species may breed in certain habitats but move across a heterogeneous habitat mosaic during the course of their daily foraging activities. Due to this, it is possible that some of the smaller and less disturbed degraded patches that were sampled, harboured some bird species that are normally restricted to good forest habitat. The painted spurfowl, for example, was seen in undisturbed habitats and less disturbed patches, but not in large-scale disturbances such as in Kankwari. During the next phase of the study, we propose to extend sampling taking the spatial scale and intensity of disturbance into account, so that these effects at different scales can be distinguished.

Reasons underlying impacts of changing habitat structure on birds

Changes in bird composition in disturbed habitats could not be linked strongly or definitively to changes in habitat features in this study, as has been possible in other studies in tropical areas (Greenberg *et al*, 1997b; Raman *et al,* 1998; Raman and Sukumar, 2002,). This could be due to the fact that not all features related to vegetation structure and composition were significantly different between disturbed and undisturbed habitats. This could be due to two reasons. One, there were great differences in structure across the four habitat types that were studied. For example, understorey density was naturally higher in scrub forest in comparison to date palm forest, even when undisturbed. Second, degraded forests of certain habitat types resembled undisturbed forests of other categories, at least in some features. For example, understorey density was high in both disturbed scrub forests (where species such as *Adhatoda vasica* reached weedy proportions) as well as in undisturbed *Anogeissus* forest (where there was a high density of saplings). Similarly, degraded date palm forest was quite different in structure from that of disturbed scrub forest. Possibly due to these reasons, sharp differentiation between disturbed and undisturbed forests was not seen.

The change in abundances of the eleven sensitive bird species appears to be related most to drastic reduction in canopy cover and loss of diverse food plants for birds, at least during the study period. This also explains the fact that change in composition of bird communities was seen most strongly in date-palm forest and mixed forest (see ordination diagram in Figure 5), which were the habitat types found to be the ones undergoing much more change in vegetation due to forest use than *Anogeissus*-dominated and scrub forest types (see Table 9).

A few other habitat features that were likely to be of importance to bird communities were overlooked during the study, such as depth of leaf litter and height of trees. Foliage height diversity was analyzed using too few sampling points (ie, twenty) due to which the vegetational diversity within each transect may not have been fully captured. During the second phase of the project, such vegetation features will be studied in more detail to complement the existing information from each of the forty sites.

Further sampling is required also for studying changes in habitat selection of birds as this could be driven partly by seasonal changes in distribution of food resources in the forest, particularly nectar and fruits. Patterns of flowering and fruiting in various vegetation associations appear to play an important role in determining bird species distributions in Sariska. For example, the insectivorous-nectarivorous guild of birds was found to be considerably reduced in abundance in disturbed habitat, obviously due to the complete absence of fruiting and flowering plants. The present study is proposed to be extended over a large part of the winter to fill these lacunae.

Landscape-level changes in habitat mosaic

During the present study, we also discovered the critical importance of the habitat mosaic of scrub, slope and riparian forest for sustaining bird communities in Sariska. The important role of the native scrub tree and shrub species in supporting bird communities during the harsh summer months was observed. For example, the flowers of kair (*Capparis decidua*) and palash (*Butea monosperma*) were fed on by a large number of bird species during the dry season, including Indian peafowl, brahminy myna and rose-ringed parakeet. In the monsoon, the pods of hingot (*Balanites aegyptiaca)* and fruits of jaal (*Capparis sepiaria*) appeared to be another important food source (see Table 7). Scrub forest, however, faces particularly heavy pressure from human collection due to the presence of evergreen species such as *Capparis sepiaria*, *Grewia robusta* and *Butea monosperma* that offer fodder during the extended dry season when few other trees and shrubs are in leaf. During the period of the study, flowering and fruiting of trees such as *Acacia leucophloea* and *Butea monosperma*, was considerably hampered in the disturbed scrub forest due to frequent lopping of vegetation. It appears that due to frequent cutting and overgrazing, such native scrub forest species are dying out in the heavily used areas of the NP and being replaced by weeds, including exotics such as *Prosopis juliflora* and *Cassia tora* (pers.obs.).

Even more important is the role of date palm-dominated riparian forest in providing nutrition and shelter to bird species during the dry season. The high diversity of tree and shrub species in the riparian zone ensures a continual supply of edible fruits such as those of rohini (*Mallotus phillippensis)*, gular (*Ficus glomerata*), tendu (*Diospyros melanoxylon*) and supply of nectar from flowers of date palm (*Phoenix sylvestris)* during the dry season (see Table 7). The mostly evergeen riparian zone also offers shelter to animal and bird species during the harsh summer months when most other habitat types are dry and leafless. Tall and leafy trees such as those of arjun (*Terminalia arjuna)*, bahera (*Terminalia bellerica*), and gular (*Ficus glomerata)* as well as dense date palms and bamboos create shade for bird species, many of which are seen only this habitat zone during this season. Peacocks were seen sheltering from the harsh sun in large numbers. Riparian zones are also important in that they harbour distinct bird communities including species such as the brown fish owl, painted spurfowl, verditer flycatcher and Tickell's blue flycatcher, that cannot survive in the more open habitat elsewhere (see also Rodgers, 1990 for insightful comments on the biological importance of riparian habitat in Sariska).

It was observed that, in comparison to other habitat types, riparian forest is most threatened in Sariska due to the pressure for livestock-grazing and biomass collection for fuelwood and fodder, particularly due to the presence of perennial springs in such places (pers. comm. Mangu Singh and pers. obs.). These areas offer green fodder for livestock in the dry season, which is extremely scarce elsewhere in the Reserve during this period. For example, we found that Algual (a site with a permanent spring) has very high potential for sustaining bird diversity but is under heavy pressure from Kirashka village from where cattle are brought in large numbers each day for grazing and watering. Evidence of habitat disturbance such as low tree density and diversity and signs of lopping, can be seen in Algual, though habitat degradation has not reached extreme proportions as in Kankwari and Umri areas. Areas with high sub-surface water and flatter terrain that appear to have had date-palm dominated semi-deciduous forest, such as Kankwari and Umri, have also been preferentially settled by people and so possibly no forest of this category remains inside Sariska.

Importance of STR for maintaining regional bird diversity

We observed large-scale roosting of passage-migratory species such as the common rosefinch, and rosy starling, in the Reserve, indicating that it may be an important stop-over point for these birds during their migrations across the Indian subcontinent. Sariska may be playing a similar role for many other species such as crested buntings, golden orioles, Indian pitta, common ioras and paradise flycatchers during their local migrations in northern India. This points to the importance of maintaining networks of natural habitats at the landscape level in the Aravallis, for enabling local and long-distance migration of birds in northern India (see also Sankar *et al.*, 1994).

Sariska appears to have healthy populations of the long-billed vulture and red-headed vulture and a small population of white-rumped vultures. This is significant in view of the observed large-scale general declines in vulture populations in India. Other raptor species such as the oriental honey buzzards, shikra, Bonelli's eagle and white-eyed buzzard also appear to have breeding populations inside Sariska. The presence of open scrub woodlands, patches of tall forest and high cliffs are ideal for the nesting and hunting of many of these raptor species. Such species, having high area requirements, are likely to disappear with further fragmentation of forests in the Aravallis or further denudation inside Sariska.

Management of human impact within Sariska

In view of the findings of the study and the observed existing pressure for biomass on forests in the Reserve, there is an acute need for providing alternatives to the villagers residing inside the Reserve. We estimate that one-third of the proposed National Park area may be severely degraded with low plant regeneration, low tree species richness, low basal areas and soil erosion and consequently, low biodiversity conservation value. This figure is an approximation based on the number of villages present inside the proposed NP and their approximate areas of impact, as observed during the study period. Provision of alternatives to biomass needs that are currently met from the forest and relocation of villages to areas outside the Reserve are possibilities that are being explored by the Rajasthan Forest Department (Government of Rajasthan, 2002) and that should be followed up in the near future.

Conclusion

Substantial impact of small scale habitat disturbance caused by intensive human use was seen on bird communities of dry deciduous and scrub forests of Sariska. Though net species diversity and bird densities were unchanged in disturbed areas, there were statistically significant differences in bird species composition between disturbed and undisturbed forest habitat. Feeding guild composition and species composition were significantly changed in disturbed forests in comparison to undisturbed forests. Graminivores were more abundant while the insectivore-nectarivores were less abundant in disturbed habitat in comparison to undisturbed habitat. Bird communities of date palm-dominated riparian forest and mixed forests were more affected by habitat degradation than those of scrub forest and Anogeissus forest. The change appears to be related to the relatively greater changes in habitat structure that accompany intensive human use in date palm forest and mixed forest in comparison to those that take place in scrub forest and Anogeissus-dominated forest. The changes in bird community composition may also be related to the lack of food resources for various species of specialized birds that inhabit undisturbed forests, during the dry season. Collection of more data is likely to reveal stronger effects of disturbance, as due to the short-term nature of the study, sufficient data on rare and cryptic species could not be collected. Since bird species are central to regeneration and therefore, to maintaining diversity of tropical dry forests, it is likely that loss of bird species may lead to a spiraling loss of overall biodiversity in the future. Growing habitat degradation due to these reasons, poses a threat to the survival of the tiger in Sariska, which harbours one of the its two reported populations in the state of Rajasthan. We suggest that urgent action be taken to stop further degradation of habitat due to biomass collection and grazing in Sariska Tiger Reserve by finding viable alternatives for local people who depend on these plant resources.

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Figure 2a to 2d
Cumulative species-effort curves for each habitat type
(Sampling days are shown on the X-axis)

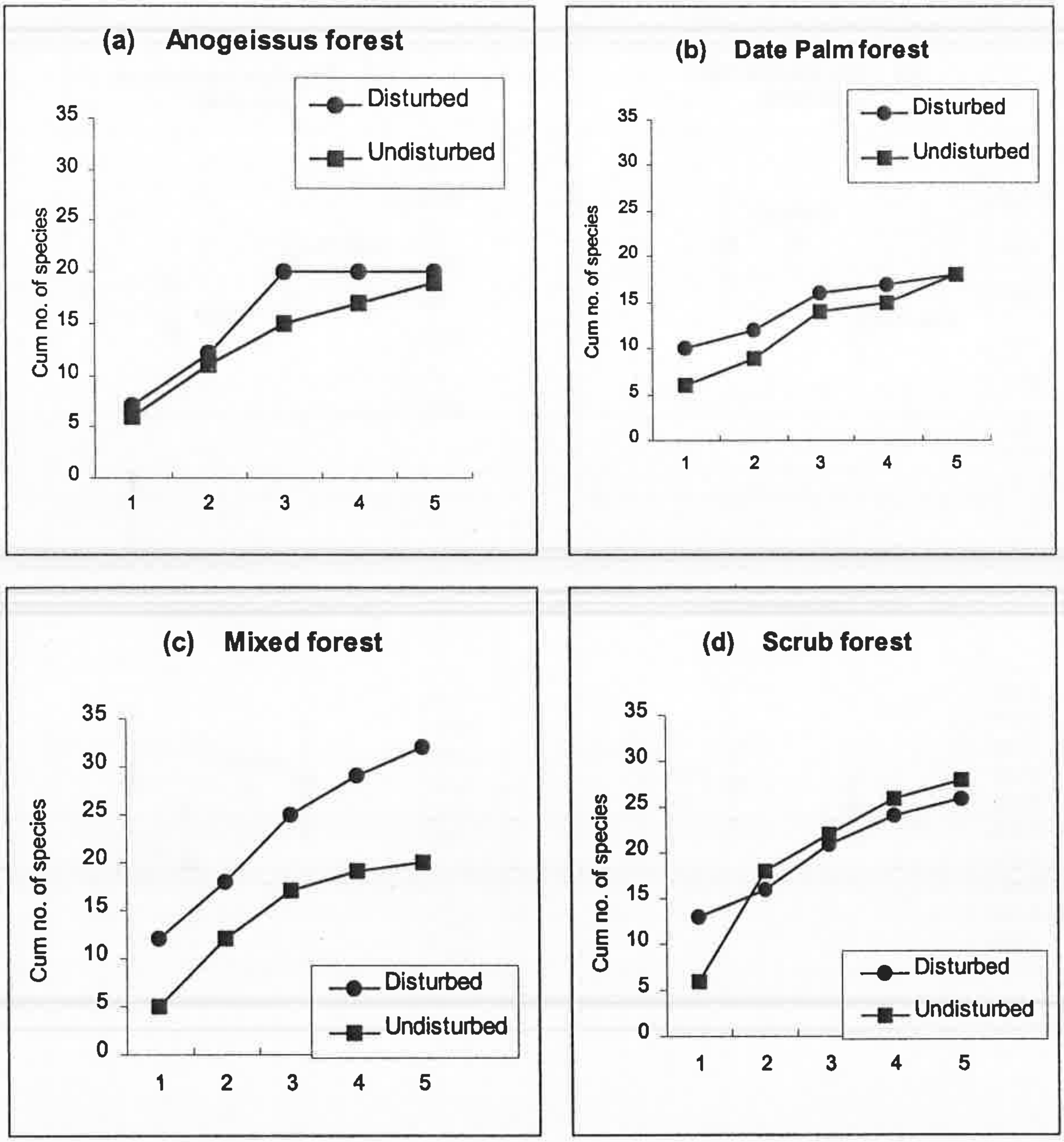

Figure 3a to 3d
Comparison of bird species diversity and abundance between disturbed and undisturbed habitats

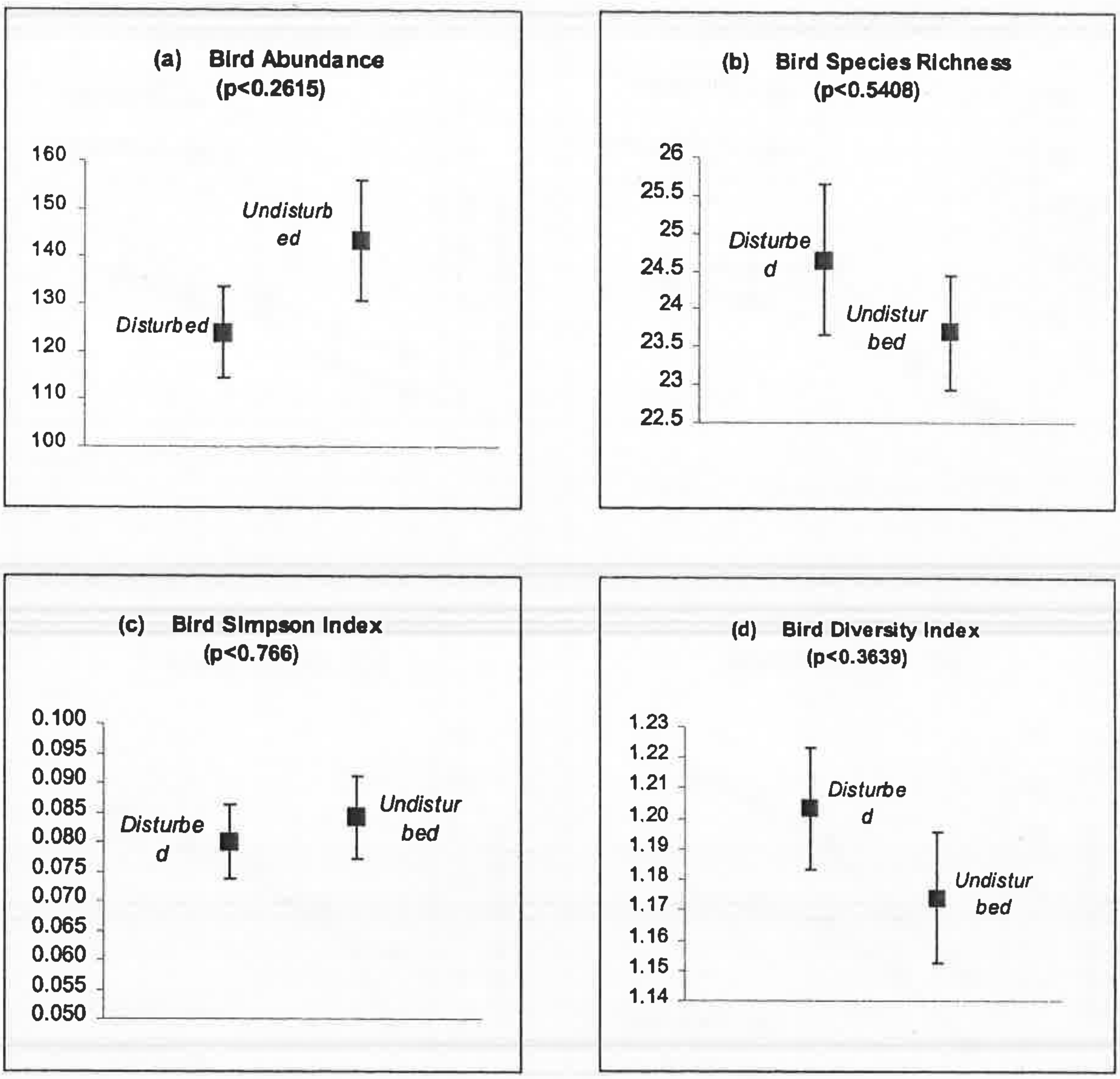

Figure 4
Rarefaction curve showing observed species richness against that predicted for each site

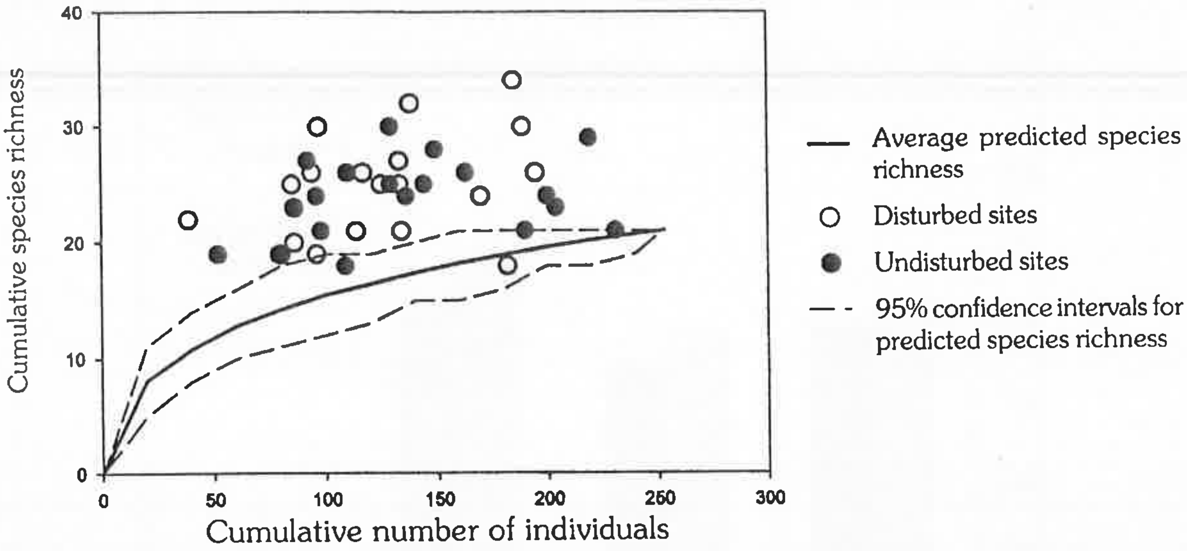

Figure 5
DCA based on bird species composition

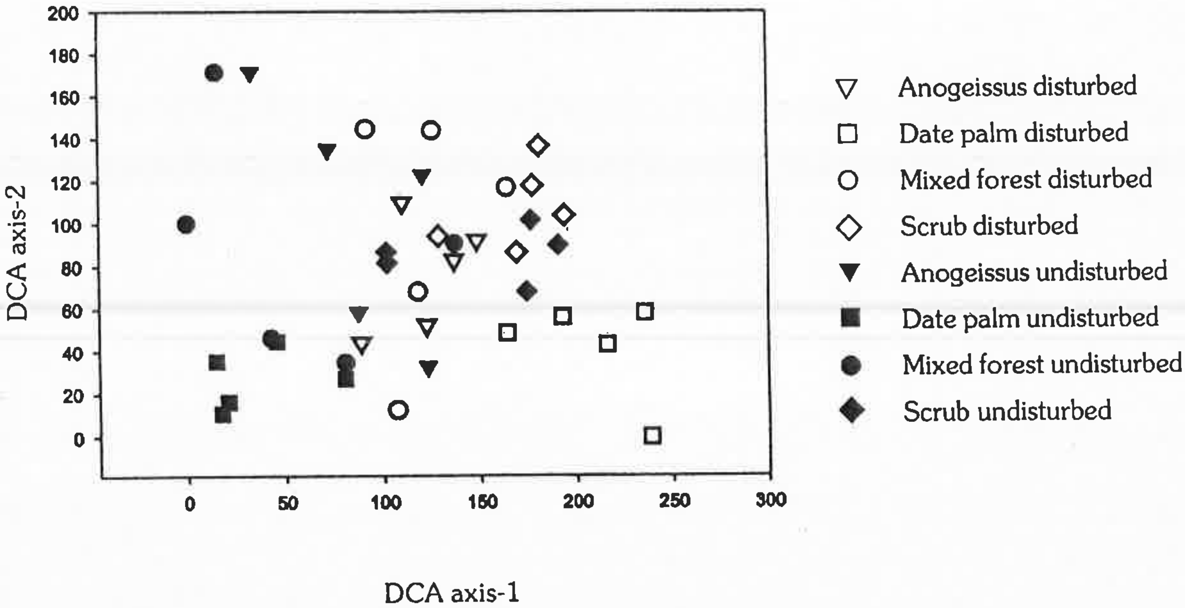

Figure 6
Similarity analysis for bird species composition

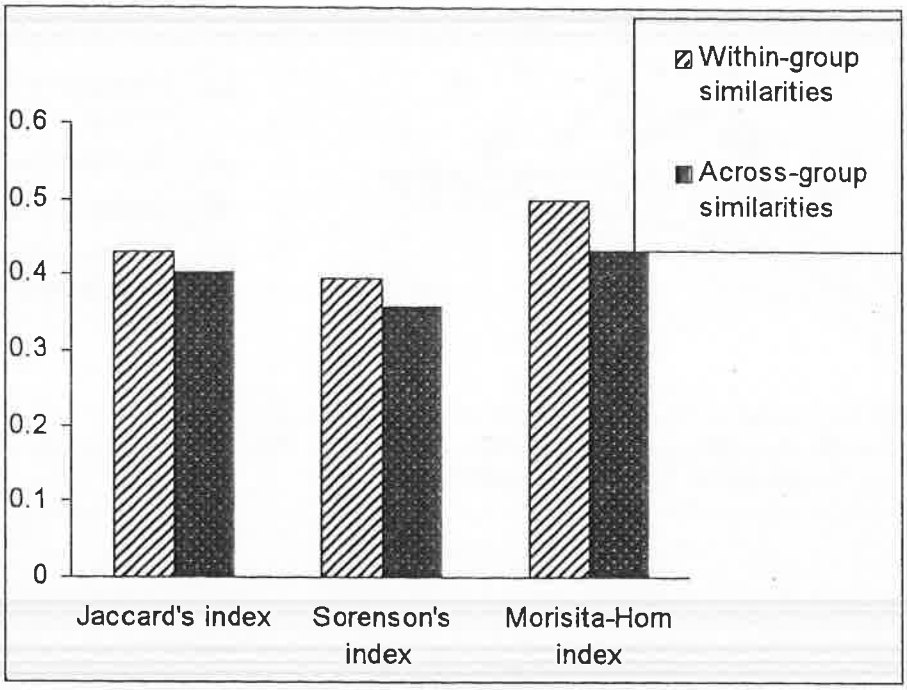

Figure 7a,b, c, d and e
Relative abundance of feeding guilds
(see Table 3 for full forms)

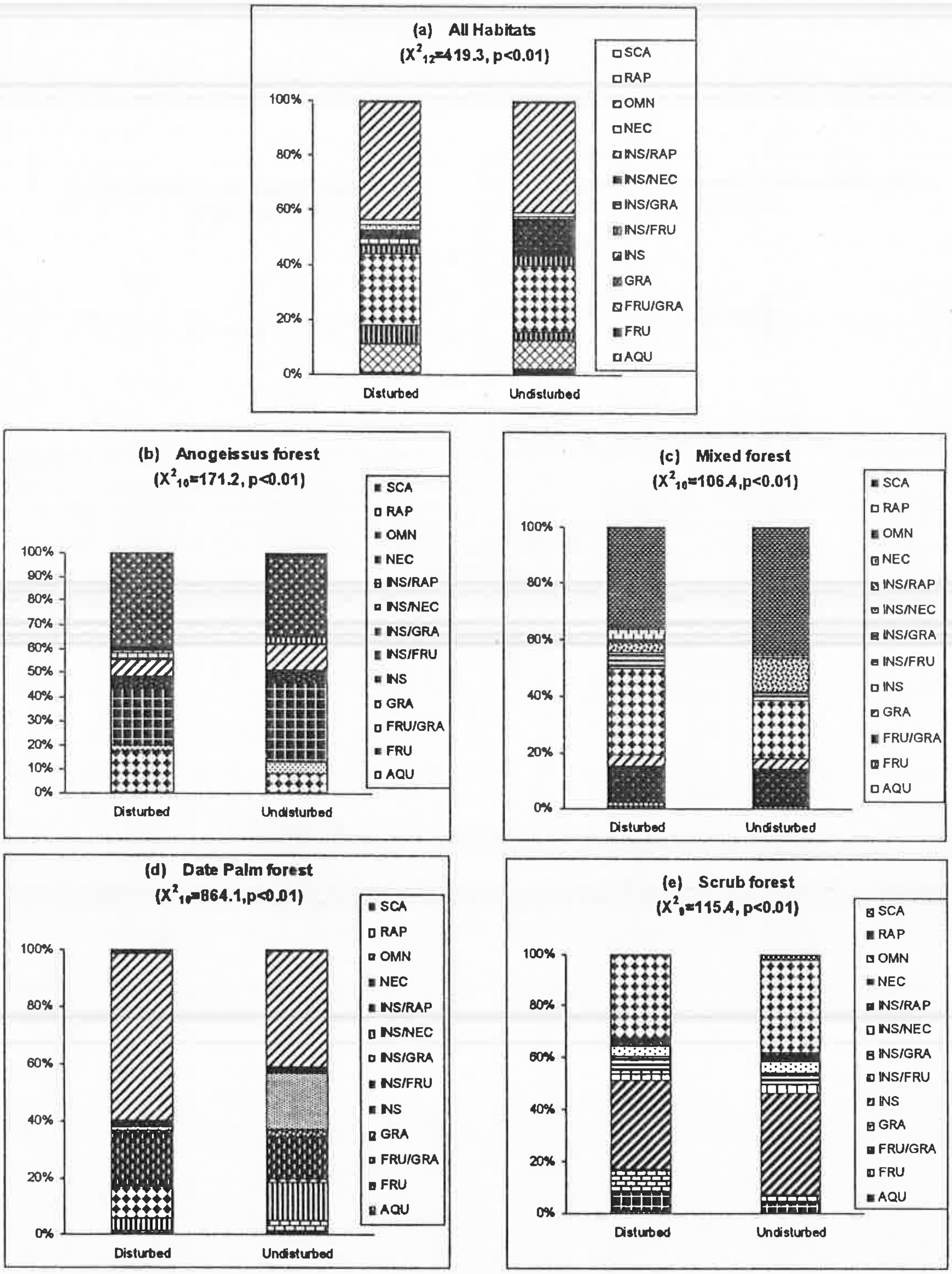

Figure 8a to 8c
Comparison of indices related to human disturbance between disturbed and undisturbed habitats

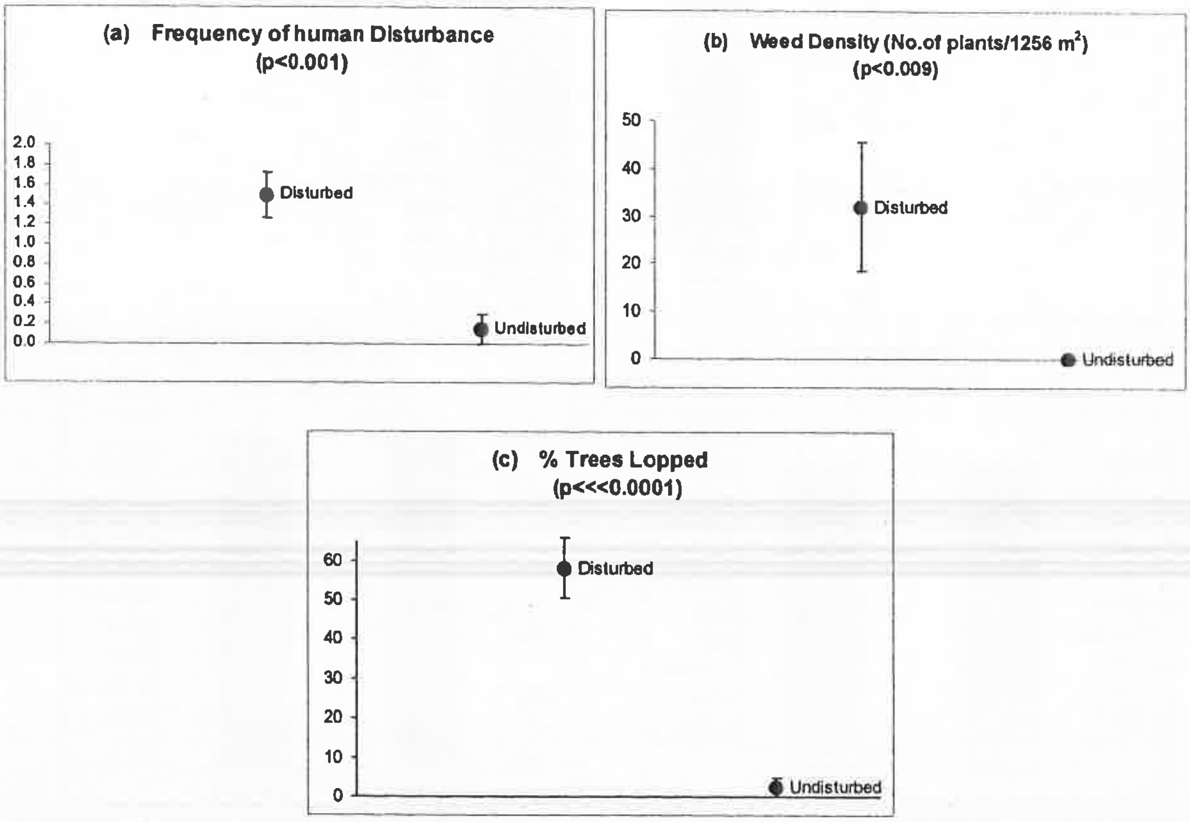

Figure 9a to 9f
Comparison of vegetation features between disturbed and undisturbed habitats

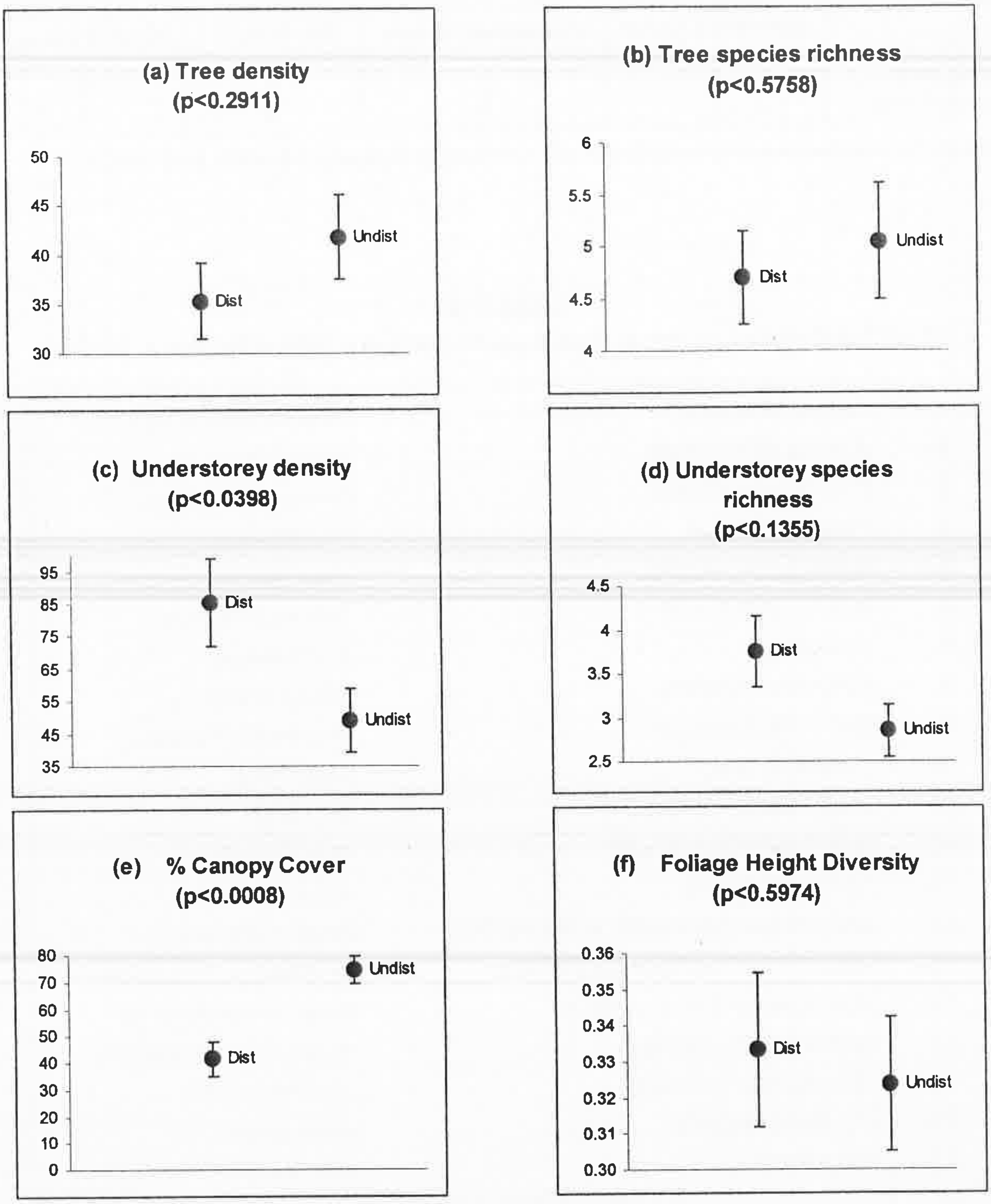

TABLE 1

Sampling scheme adopted for studying the impact of habitat degradation on bird communities

	Date palm forest	*Anogeissus* forest	Scrub forest	Mixed Forest
Disturbed	5	5	5	5
Undisturbed	5	5	5	5

Note: The number in each box indicates the number of transects sited within each category

TABLE 2

List of bird species recorded inside Sariska (March-June 2003)

1.	GREY FRANCOLIN	*Francolinus pondicerianus*
2.	JUNGLE BUSH QUAIL	*Perdicula asiatica*
3.	PAINTED SPURFOWL	*Galloperdix lunulata*
4.	INDIAN PEAFOWL	*Pavo cristatus*
5.	BAR-HEADED GOOSE	*Anser indicus*
6.	RUDDY SHELDUCK	*Tadorna ferruginea*
7.	GADWALL	*Anas strepera*
8.	EURASIAN WIGEON	*Anas penelope*
9.	SPOT -BILLED DUCK	*Anas poecilorhyncha*
10.	COMMON TEAL	*Anas crecca*
11.	NORTHERN PINTAIL	*Anas acuta*
12.	NORTHERN SHOVELLER	*Anas clypeata*
13.	BAER'S POCHARD	*Aythya baeri*
14.	BROWN-CAPPED PYGMY WOODPECKER	*Dendrocopos nanus*
15.	YELLOW-CROWNED WOODPECKER	*Dendrocopos mahrattensis*
16.	BLACK-RUMPED FLAMEBACK	*Dinopium benghalense*
17.	COPPERSMITH BARBET	*Megalaima haemacephala*
18.	INDIAN GREY HORNBILL	*Ocyceros birostris*
19.	COMMON HOOPOE	*Upupa epops*
20.	INDIAN ROLLER	*Coracias benghalensis*

TABLE 2 (Contd.)

21.	WHITE- THROATED KINGFISHER	*Halcyon smyrnensis*
22.	PIED KINGFISHER	*Ceryle rudis*
23.	GREEN BEE-EATER	*Merops orientalis*
24.	BLUE- TAILED BEE-EATER	*Merops philippinus*
25.	PIED CUCKOO	*Clamator jacobinus*
26.	EURASIAN CUCKOO	*Cuculus canorus*
27.	ASIAN KOEL	*Eudynamys scolopacea*
28.	GREATER COUCAL	*Centropus sinensis*
29.	ROSE-RINGED PARAKEET	*Psittacula krameri*
30.	PLUM-HEADED PARAKEET	*Psittacula cyanocephala*
31.	HOUSE SWIFT	*Apus affinis*
32.	COLLARED SCOPS OWL	*Otus bakkamoena*
33.	BROWN FISH OWL	*Ketupa zeylonensis*
34.	SPOTTED OWLET	*Athene brama*
35.	GREY NIGHT JAR	*Caprimulgus indicus*
36.	SYKES'S NIGHT JAR	*Caprimulgus mahrattensis*
37.	INDIAN NIGHT JAR	*Caprimulgus asiaticus*
38.	ROCK PIGEON	*Columba livia*
39.	LAUGHING DOVE	*Streptopelia senegalensis*
40.	SPOTTED DOVE	*Streptopelia chinensis*
41.	RED COLLARED DOVE	*Strptopelia tranquebarica*
42.	EURASIAN COLLARED DOVE	*Streptopelia decaocto*
43.	YELLOW-FOOTED GREEN PIGEON	*Treron phoenicoptera*
44.	SARUS CRANE	*Grus antigone*
45.	WHITE-BREASTED WATERHEN	*Amaurornis phoenicurus*
46.	COMMON COOT	*Fulica atra*
47.	COMMON SNIPE	*Gal1inago gallinago*
48.	BLACK- TAILED GODWIT	*Limosa limosa*
49.	COMMON REDSHANK	*Tringa totanus*
50.	COMMON GREENSHANK	*Tringa nebularia*
51.	GREEN SANDPIPER	*Tringa ochorpus*
52.	WOOD SANDPIPER	*Tringa glareola*

TABLE 2 (Contd.)

53.	COMMON SANDPIPER	*Actitis hypoleucos*
54.	LITTLE STINT	*Calidris minuta*
55.	TEMMINCK'S STINT	*Calidris temminckii*
56.	EURASIAN THICK-KNEE	*Burhinus oedicnemus*
57.	BLACK WINGED STILT	*Himantopus himantopus*
58.	LITTLE RINGED PLOVER	*Charadrius dubius*
59.	YELLOW-WATTLED LAPWING	*Vanellus malabaricus*
60.	RED-WATTLED LAPWING	*Vanellus indicus*
61.	RIVER TERN	*Sterna aurantia*
62.	BLACK-BELLIED TERN	*Sterna acuticauda*
63.	WHISKERED TERN	*Chlidonias hybridus*
64.	EGYPTIAN VUL TURE	*Neophron percnopterus*
65.	WHITE-RUMPED VUL TURE	*Gyps bengalensis*
66.	LONG-BILLED VUL TURE	*Gyps indicus*
67.	RED-HEADED VUL TURE	*Sarcogyps calvus*
68.	CRESTED SERPENT EAGLE	*Spilornis cheela*
69.	SHIKRA	*Accipiter badius*
70.	EURASIAN SPARROWHAWK	*Accipiter nisus*
71.	ORIENTAL HONEY-BUZZARD	*Pernis ptilorhyncus*
72.	WHITE-EYED BUZZARD	*Butastur teesa*
73.	STEPPE EAGLE	*Aquila nipalensis*
74.	BONELLI'S EAGLE	*Hieraaetus fasciatus*
75.	LITTLE GREBE	*Tachybaptus ruficollis*
76.	LITTLE CORMORANT	*Phalacrocorax niger*
77.	INDIAN CORMORANT	*Phalacrocorax fuscicollis*
78.	LITTLE EGRET	*Egretta garzetta*
79.	GREAT EGRET	*Casmerodius albus*
80.	INTERMEDIATE EGRET	*Mesophoyx intermedia*
81.	CATTLE EGRET	*Bubulcus ibis*
82.	INDIAN POND HERON	*Ardeola gray*
83.	GREY HERON	*Ardea cinerea*
84.	BLACK-CROWNED NIGHT HERON	*Nycticorax nycticorax*

TABLE 2 (Contd.)

85.	BLACK-HEADED IBIS	*Threskiornis melanocephalus*
86.	EURASIAN SPOONBILL	*Platalea leucorodia*
87.	GREAT WHITE PELICAN	*Pelecanus onocrotalus*
88.	PAINTED STORK	*Mycteria leucocephala*
89.	ASIAN OPENBILL	*Anastomus oscitans*
90.	WOOLL Y-NECKED STORK	*Ciconia episcopus*
91.	BAY-BACKED SHRIKE	*Lanius vittatus*
92.	LONG- TAILED SHRIKE	*Lanius schach*
93.	RUFOUS TREEPIE	*Dendrocitta vagabunda*
94.	HOUSE CROW	*Corvus splendens*
95.	LARGE-BILLED CROW	*Corvus macrorhynchos*
96.	EURASIAN GOLDEN ORIOLE	*Oriolus oriolus*
97.	LARGE CUCKOOSHRIKE	*Coracina mace*
98.	BLACK HEADED CUCKOOSHRIKE	*Coracina melanoptera*
99.	SMALL MINIVET	*Pericrocotus cinnamomeus*
100.	WHITE-BROWED FANTAIL FL YCATCHER	*Rhipidura aureola*
101.	BLACK DRONGO	*Dicrurus macrocercus*
102.	WHITE-BELLIED DRONGO	*Dicrurus caerulescens*
103.	ASIAN PARADISE-FL YCATCHER	*Terpsiphone paradisi*
104.	COMMON IORA	*Aegithina tiphia*
105.	COMMON WOODSHRIKE	*Tephrodornis pondicerianus*
106.	RED- THROATED FL YCATCHER	*Ficedula parva*
107.	LITTLE PIED FL YCA TCHER	*Ficedula westermanni*
108.	VERDITER FL YCATCHER	*Eumyias thalassina*
109.	TICKELL'S BLUE FL YCATCHER	*Cyornis tickelliae*
110.	ORIENTAL MAGPIE ROBIN	*Copsychus saularis*
111.	INDIAN ROBIN	*Saxicoloides tulicata*
112.	BLACK REDST ART	*Phoenicurus ochruros*
113.	COMMON STONECHAT	*Saxicola torquata*
114.	BROWN ROCK-CHAT	*Cercomela tusca*
115.	BRAHMINY ST ARLING	*Sturnus pagodarum*
116.	ASIAN PIED STARLING	*Sturnus contra*

TABLE 2 (Contd.)

117.	ROSY STARLING	*Sturnus rose us*
118.	COMMON MYNA	*Acridotheres tristis*
119.	BANK MYNA	*Acridotheres ginginianus*
120.	GREAT TIT	*Parus major*
121.	DUSKY CRAG MARTIN	*Hirundo con color*
122.	WIRE- TAILED SWALLOW	*Hirundo smithii*
123.	RED-RUMPED SWALLOW	*Hirundo daurica*
124.	RED-VENTED BULBUL	*Pycnonotus cater*
125.	GREY-BREASTED PRINIA	*Prinia hodgsonii*
126.	JUNGLE PRINIA	*Prinia sylvatica*
127.	PLAIN PRINIA	*Prinia inornata*
128.	ASHY PRINIA	*Prinia socialis*
129.	ORIENTAL WHITE-EYE	*Zosterops palpebrosus*
130.	BOOTED WARBLER	*Hippolais caligata*
131.	LESSER WHITETHROAT	*Sylvia curruca*
132.	COMMON TAILORBIRD	*Orthotomus sutorius*
133.	COMMON CHIFFCHAFF	*PhyJloscopus collybita*
134.	YELLOW-EYED BABBLER	*Chrysomma sinense*
135.	COMMON BABBLER	*Turdoides caudatus*
136.	LARGE GREY BABBLER	*Turdoides malcolmi*
137.	JUNGLE BABBLER	*Turdoides striatus*
138.	RUFOUS- TAILED LARK	*Ammomanes phoenicurus*
139.	PURPLE SUNBIRD	*Nectarinia asiatica*
140.	HOUSE SPARROW	*Passer domesticus*
141.	CHESTNUT -SHOULDERED PETRONIA	*Petronia xanthocollis*
142.	WHITE WAGTAIL	*Motacilla alba*
143.	CITRINE WAGTAIL	*Motacilla citreola*
144.	GREY WAGTAIL	*Motacilla cinerea*
145.	TAWNY PIPIT	*Anthus campestris*
146.	TREE PIPIT	*Anthus trivialis*
147.	BA Y A WEA VER	*Ploceus philippinus*
148.	COMMON ROSEFINCH	*Carpodacus erythrinus*
149.	CRESTED BUNTING	*Melophus lathami*

TABLE 3
Feeding Guilds Assigned to Bird Species

No.	Common Name	Guild
1	Grey Francolin	INS/GRA
2	Painted Spurfowl	INS/FRU
3	Indian Peafowl	OMN
4	Brown-Capped Pygmy Woodpecker	INS/NEC
5	Yellow-Crowned Woodpecker	INS
6	Comon Hoopoe	INS
7	Indian Roller	INS/RAP
8	White-Throated Kingfisher	INS/RAP
9	Green Bee-Eater	INS
10	Blue-Tailed Bee-Eater	INS
11	Asian Koel	INS/FRU
12	Greater Coucal	INS/RAP
13	Rose-Ringed Parakeet	FRU/GRA
14	Plum-Headed Parakeet	FRU/GRA
15	Spotted Owlet	INS/RAP
16	Indian Nightjar	INS
17	Rock Pigeon	GRA
18	Laughing Dove	GRA
19	Spotted Dove	GRA
20	Red Collared Dove	GRA
21	Eurasian Collared Dove	GRA
22	Yellow-Footed Green Pigeon	FRU
23	White-Breasted Waterhen	AQU
24	Common Greenshank	AQU
25	Red-wattled Lapwing	INS
26	Egyptian Vulture	SCA
27	White-Rumped Vulture	SCA
28	Long-Billed Vulture	SCA
29	Red-Headed Vulture	SCA

TABLE 3 (Contd.)

No.	Common Name	Guild
30	Shikra	RAP
31	Oriental Honey-Buzzard	INS/RAP
32	White-Eyed Buzzard	INS/RAP
33	Bonelli's eagle	RAP
34	Little Cormorant	AQU
35	Little Egret	AQU
36	Indian Pond Heron	AQU
37	Bay-Backed Shrike	INS
38	Long-Tailed Shrike	INS
39	Rufous Treepie	OMN
40	House Crow	OMN
41	Large-Billed Crow	OMN
42	Eurasian Golden Oriole	INS/FRU
43	Small Minivet	INS
44	White Browed Fantail Flycatcher	INS
45	Black Drongo	INS
46	White-Bellied Drongo	INS
47	Asian Paradise-Flycatcher	INS
48	Common Iora	INS
49	Common Woodshrike	INS
50	Ticklle's Blueflycatcher	INS
51	Oriental Magpierobin	INS
52	Indian Robin	INS
53	Black Redstart	INS
54	Brown Rock-Chat	INS
55	Brahminy Starling	OMN
56	Asian Pied Starling	OMN
57	Comon Myna	OMN
58	Bank Myna	OMN
59	Great Tit	OMN
60	Red-Rumped Swallow	INS

TABLE 3 (Contd.)

No.	Common Name	Guild
61	Red-Vented Bulbul	OMN
62	Grey-Breasted Prinia	INS/NEC
63	Jungle Prinia	INS
64	Plain Prinia	INS/NEC
65	Oriental White-Eye	INS/NEC
66	Booted warbler	INS
67	Lesser Whitethroat	INS/NEC
68	Common Tailorbird	INS/NEC
69	Yellow-Eyed Babbler	INS
70	Common Babbler	OMN
71	Large Grey Babbler	OMN
72	Jungle Babbler	INS
73	Purple Sunbird	NEC
74	House Sparrow	OMN
75	Chestnut-Shouldered Petronia	OMN
76	White Wagtail	INS
77	Baya Weaver	GRA
78	Crested Bunting	GRA

Key:
AQU Aquatic
FRU Frugivorous
FRU-GRA Frugivore-Granivore
GRA Granivore
INS Insectivore
INS-FRU Insectivore-frugivore
INS-GRA Insectivore-granivore
INS-NEC Insectivore-nectarivore
INS-RAP Insectivore
NEC Nectarivore
OMN Omnivore
RAP Raptor
SCA Scavenger

TABLE 4

Difference in Bird Species Abundances between Disturbed and Undisturbed habitat

No:	Common name	Average Density in Disturbed	Average Density-Undisturbed	Significance level
1	Asian Koel	0.3	0.2	
2	Asian Paradise-Flycatcher	0.6	0.8	
3	Asian Pied Starling	0.2	0.0	
4	Bank Myna	0.2	0.0	
5	Bay-Backed Shrike	0.5	1.8	
6	Black Drongo	5.0	3.2	*
7	Black Redstart	0.1	0.5	
8	Black-Rumped Flameback	1.6	0.7	
9	Blue-tailed Bee-eater	0.1	0.0	
10	Bonelli's Eagle	0.0	0.1	
11	Booted Warbler	0.1	0.0	
12	Brahminy Starling	5.0	4.3	
13	Brown Rock-Chat	0.1	0.6	
14	Brown-capped Pygmy Woodpecker	0.2	0.6	*
15	Chestnut-shouldered Petronia	3.7	2.4	
16	Common Babbler	1.5	0.6	
17	Common Greenshank	0.1	0.0	
18	Common Hoopoe	0.2	0.0	
19	Common Iora	0.1	0.0	
20	Common Myna	13.4	4.5	**
21	Common Tailorbird	1.4	1.7	
22	Common Woodshrike	0.1	0.7	**
23	Crested Bunting	0.3	0.7	
24	Egyptian Vulture	0.4	0.0	
25	Eurasian Collared Dove	3.1	0.3	***
26	Eurasian Golden Oriole	3.4	3.7	
27	Great Tit	1.6	3.9	*

TABLE 4 (Contd.)

No:	Common name	Average Density in Disturbed	Average Density-Undisturbed	Significance level
28	Greater Coucal	1.2	0.4	**
29	Green Bee-eater	0.4	0.1	
30	Grey Francolin	2.7	1.8	
31	Grey-breasted Prinia	0.0	0.9	*
32	House Crow	6.5	1.2	***
33	House Sparrow	1.0	0.0	**
34	Indian Nightjar	0.0	0.1	
35	Indian Peafowl	9.6	14.2	
36	Indian Pond Heron	0.0	0.1	
37	Indian Robin	8.2	3.6	**
38	Indian Roller	0.2	0.0	
39	Jungle Babbler	6.0	9.6	
40	Jungle Prinia	0.1	0.0	
41	Large Grey Babbler	0.9	0.3	
42	Large-billed Crow	0.0	0.1	
43	Laughing Dove	2.1	0.9	
44	Lesser Whitethroat	0.4	0.1	
45	Little Cormorant	0.0	0.1	
46	Little Egret	0.1	0.0	
47	Long-billed Vulture	0.1	1.0	
48	Long-tailed Shrike	0.5	0.2	
49	Oriental Honey-buzzard	0.1	0.5	
50	Oriental Magpie Robin	0.9	3.5	***
51	Oriental White-eye	1.6	14.6	***
52	Painted Spurfowl	0.4	0.7	
53	Plain Prinia	0.5	0.3	
54	Plum-headed Parakeet	1.4	2.7	
55	Purple Sunbird	2.0	2.0	
56	Red Collared Dove	0.4	0.1	

TABLE 4 (Contd.)

No:	Common name	Average Density in Disturbed	Average Density-Undisturbed	Significance level
57	Red-headed Vulture	0.0	0.1	
58	Red-rumped Swallow	0.8	0.4	
59	Red-Vented Bulbul	7.6	18.3	***
60	Red-Wattled Lapwing	2.1	0.6	
61	Rock Pigeon	0.7	0.9	
62	Rose-Ringed Parakeet	10.8	12.3	
63	Rufous Treepie	3.0	7.7	***
64	Shikra	0.0	0.2	*
65	Small Minivet	2.5	3.4	
66	Spotted dove	2.2	1.3	
67	Spotted Owlet	0.8	0.2	**
68	Tickell's Blue Flycatcher	0.0	0.4	
69	White Wagtail	0.3	0.0	
70	White-bellied Drongo	0.6	1.8	*
71	White-breasted Waterhen	0.1	0.0	
72	White-browed Fantail	1.2	3.8	***
73	White-eyed Buzzard	0.1	0.0	
74	White-rumped Vulture	0.0	0.1	
75	White-throated Kingfisher	0.2	0.2	
76	Yellow-crowned Woodpecker	0.6	0.1	**
77	Yellow-eyed Babbler	0.1	0.0	
78	Yellow-footed Green Pigeon	1.3	3.0	

Significance levels:
* $p<0.10$
** $p<0.05$
*** $p<0.01$

TABLE 5

Presence-absence table for bird species seen 10 times or less

No.	Species	Disturbed					Undisturbed			
		A	D	M	S		A	D	M	S
1	Bank Myna		■							
2	Bonelli's Eagle							■		
3	Booted Warbler				■					
4	Blue-tailed Bee-eater				■					
5	Common Iora			■						
6	Egyptian Vulture		■							
7	Common Greenshank		■							
8	Oriental Honey-buzzard	■					■	■		■
9	Common Hoopoe		■							
10	Indian Night jar						■		■	
11	Indian Roller		■							
12	Large-billed Crow						■			
13	Jungle Prinia	■		■						
14	Red-headed Vulture						■			
15	Asian Koel	■		■	■			■		■
16	Little Cormorant							■		
17	Little Egret		■							
18	Lesser Whitethroat			■	■		■		■	
19	White Wagtail		■							
20	Asian Pied Starling		■							
21	Indian Pond Heron							■		
22	Black Redstart		■					■		■
23	Red Collared Dove		■	■						■
24	Green Bee-eater	■		■	■			■		■
25	Shikra							■	■	
26	Tickell's Blue Flycatcher							■	■	
27	White-breasted Waterhen		■							
28	White-throated Kingfisher	■	■	■				■		
29	White-rumped Vulture									■
30	White-eyed Buzzard	■								
31	Yellow-eyed Babbler				■					

Key:
A: Anogeissus forest
D: Date palm Forest
M: Mixed Forest
S: Scrub Forest

Note: Black fill indicates presence

TABLE 6

Presence-Absence Table for Bird Species seen Outside Transects

No.	Species	D	U	Habitat Type
1	Jungle Bush Quail	■		S
2	Bar-Headed Goose	■		W/C
3	Ruddy Shelduck	■		W
4	Gadwall	■		W
5	Eurasian Wigeon	■		W
6	Spot-Billed Duck	■		W
7	Comon Teal	■		W
8	Northern Pintail	■		W
9	Northern Shoveler	■		W
10	Baer's Pochard	■		W
11	Coppersmith Barbet	■		S
12	Indian Grey Hornbill	■		M
13	Pied Kingfisher	■		W
14	Blue-Tailed Bee-Eater	■		S
15	Pied Cuckoo		■	S
16	Eurasian Cuckoo		■	A
17	House Swift	■		W
18	Collared Scops Owl		■	M
19	Brown Fish Owl		■	D
20	Grey Night jar		■	A
21	Sykes's Night jar	■		S
22	Sarus Crane	■		C/W
23	Common Coot	■		W
24	Common Snipe	■		W
25	Black-Tailed Godwit	■		W
26	Common Red Shank	■		W
27	Green Sandpiper	■		W
28	Wood Sandpiper	■		W
29	Common Sandpiper	■		W
30	Little Stint	■		W
31	Temminck's Stint	■		W
32	Eurasian Thick-Knee	■		S
33	Black Winged Stilt	■		W
34	Little Ringed Plover	■		W

TABLE 6 (Contd.)

No.	Species	D	U	Habitat Type
35	Yellow-Wattled Lapwing	■		W
36	River Tern	■		W
37	Black-Bellied Tern	■		W
38	Whiskered Tern	■		W
39	Crested Serpent eagle	■	■	M
40	Eurasian Sparrowhawk		■	S/M
41	Steppe eagle		■	A/M
42	Little Grebe	■		W
43	Indian Cormorant	■		D
44	Great Egret	■		W
45	Intermediate egret	■		W
46	Cattle Egret	■		D
47	Grey Heron	■		W
48	Black-Crowned Night Heron		■	W
49	Black-Headed Ibis	■		W
50	Eurasian Spoonbill	■		W
51	Great White Pelican	■		W
52	Painted Stork	■		W
53	Asian Openbill	■		W
54	Woolly-Necked Stork	■		W
55	Large Cuckooshrike	■		S/M
56	Black Headed Cuckoo Shrike		■	S
57	Red Throated Flycatcher	■		S/A
58	little Pied Flycatcher		■	M
59	Verditer Flycatcher		■	M
60	Common Stonechat	■		S
61	Rosy Starling	■		S
62	Dusky Crag Martin		■	W
63	Wire-Tailed Swallow	■		S
64	Ashy Prinia	■		S
65	Common Chiffchaff	■		S
66	Rufous-Tailed Lark	■		S
67	Citrine Wagtail	■		W
68	Grey Wagtail	■		W
69	Tawny Pipit	■		S
70	Tree Pipit	■		S
71	Common Rosefinch	■		S

Key
D: Disturbed Habitat
U: Undisturbed Habitat
W: Wetland
S: Scrub forest
M: Mixed forest
D: Date Palm forest
A: Anogeissus forest

TABLE 7
Important Food Plants for Birds in Sariska Tiger Reserve

Acacia leucophloea:
Pods: Rose-ringed parakeet

Adhatoda vasica
Flower nectar: Purple sunbird

Butea monosperma
Pods: Rose-ringed parakeet
Flower nectar: Rose-ringed parakeet, peafowl, purple sunbird, white-eye
Flower petals: Red-vented bulbul, chestnut-shouldered petronia, brahminy mynah, peafowl, rose-inged parakeet

Capparis decidua
Flower/flower nectar: Rose-ringed parakeet, chestnut-shouldered petronia
Fruits: Rosy starling

Capparis sepiaria
Fruits: Rose-ringed parakeet

Bauhinia variegata
Flower nectar: Purple sunbird

Cassia fistula
Flower nectar: Purple sunbird, chestnut-shouldered petronia, brown-capped pygmy woodpecker
Flower petals: Red-vented bulbul

Date Palm
Flower nectar: Purple sunbird, white-eye
Fruits: Treepie, red-vented bulbul, common mynah, koel, great tit

Ficus spp.
Fruits: Rose-ringed parakeet, treepie, red-vented bulbul, plum-headed parakeet

Ficus glomerata
Fruits: Green pigeon

Gurjan
Fruits: Rose-ringed parakeet, red-vented bulbul, plum-headed parakeet

Lesua
Fruits: peafowl

Mallotus phillipensis
Fruits: Treepie
Seeds: Red-vented bulbul

Table 8
Correlation coefficients calculated between bird species abundances and vegetation features

	Common Wood Shrike	Grey-breasted Prinia	Great Tit	Oriental Magpie Robin	Brown-capped Pygmy Wood-pecker	Red-vented Bulbul	Shikra	Rufous Treepie	White-bellied Drongo	White-browed Fantail Flycatcher	Oriental White-eye
% trees lopped	-0.28	* -0.22	* -0.34	* -0.43	-0.21	* -0.31	-0.23	* -0.38	-0.28	* -0.37	*-0.37
Human disturbance	-0.17	-0.21	* -0.36	* -0.31	-0.23	-0.19	-0.22	* -0.36	-0.15	* -0.31	*-0.3
Weed density	-0.16	-0.09	-0.09	-0.07	-0.14	-0.16	-0.1	-0.26	-0.06	-0.13	-0.16
Tree density	0.05	-0.1	* 0.36	0.05	0.1	0.28	0.31	0.11	0.27	-0.05	* 0.43
Tree species richness	-0.13	0.18	* 0.44	* 0.45	0.18	* 0.48	0.27	* 0.41	0.28	* 0.34	* 0.37
Understorey density	0.14	-0.13	0.01	0.004	-0.04	* -0.39	-0.17	* -0.45	-0.03	-0.2	* -0.37
Understorey richness	0.01	0.04	0.06	0.09	-0.06	-0.08	0.006	-0.02	-0.03	-0.01	-0.13
Foliage height diver	0.03	0.23	-0.03	-0.001	0.002	-0.09	-0.17	0.06	-0.002	0.007	-0.24
Canopy cover	0.25	-0.07	* 0.57	* 0.45	* 0.33	0.15	0.26	0.21	* 0.41	* 0.3	* 0.47

Note: Correlations significant at 5% significance level are marked with an asterisks.