DISCUSSION

Habitat Diversity and Disturbance

The landscapes in arid and semi-arid regions are highly degraded due to activities such as (i) Agriculture, (ii) Human Habitation, (iii) Grazing, (iv) Lopping of trees and shrubs, (v) Road Construction, (vi) Dumping Ground. Using arbitrary scores as measures of intensity of each of these 6 identified activities, a cumulative relative impact factor (RIF) was calculated for each of three regions (Nahargarh Biological Park, Jal Mahal Forest and Kukas Forest) of Nahargarh Wildlife Sanctuary as study sites selected. The intensity of each of the 6 disturbance factors varied across the three regions and the cumulative relative impact factor (RIF) varied from 4 to 16 across the three habitats sampled (Table 14). To find out whether the observed disturbance pattern is related to the proximity of the regions to human settlements, the RIF values were plotted against the distance of human settlement from the forest border. The results indicate the statistically significant negative relationships between RIF and distance (Figure 9). This suggests that the closer the human settlement to the habitat, the greater is its disturbance. Of the three regions sampled, the Kukas Forest is closest to the human settlement and hence considered as highly disturbed (with RIF of 16), whereas Nahargarh Biological Park is far away from the human settlement and hence it is considered least disturbed (with RIF of 4); the Jal Mahal Forest is moderately disturbed (with RIF of 10) because it is neither close nor far away from the human settlement. Similar relationships have also been reported earlier by Sharma (2004).
Edaphic Gradient across the Landscape

To understand the impacts of disturbance on soil characteristics of the three habitats, the edaphic gradient across the landscape was analysed. The soils of all the three regions fall under the textural class of sandy or sandy loam. Such soils are found in the arid and semi-arid regions (Bharucha and Meher-Homji, 1965). The soil pH varied from 6.6 to 6.8, across the habitats suggesting that the soils are slightly acidic or slightly alkaline. Similar range of variation in soil pH has been reported for semi-arid regions by other workers (Janardhanan, 2002; Sinha Roy, 2002; Kipgen, 2001; Sharma 2004). The fact that these soils have a pH close to neutral range inspite of high amounts of organic matter suggests that the soils are highly buffered (Sharma, 2004). The high per cent organic matter (7.52 per cent to 7.77 percent) in soils of semi-arid regions is unusual, as the reported earlier values were in the range of 0.5 to 3.5% (Janardhanan, 2002; Sinha Roy, 2002; Sharma 2004). It is difficult to explain such high levels of organic matter content in the soils of the habitats sampled. It is likely that the enrichment of organic matter might be due to anthropogenic activities such as dumping of bio-wastes, defecation by grazing animals and roosting birds. Similar observations have been made by Weir (1969) and Moore (1983).

The nitrate, phosphate and potassium levels were also very high in the habitats sampled (Figures 12, 13 and 14) as compared to the levels reported for arid soils (Sharma, 2004). In other words the soils are nutritionally rich.
There was no nutrient gradient across the habitats. This is evident from the marginal differences in nutrient levels among the habitats (Figures 10, 11, 12, 13 and 14). These observations suggest that the size of each habitat is too small to have a distinct profile; it is likely that the habitats of the three regions are contiguous of the same landscape with free movement of grazing livestock. Infact, the mobility of nutrients across the habitats through herbivores has been reported by Edwards and Hollis (1982).

The role of disturbance on the nutrient dynamics of the habitat sampled is unlikely as the relationships of soil pH, percent organic matter and NPK levels with RIF and distance of human settlement from forest border were statistically nonsignificant at p<0.05 (Figures 15 and 16). The nutrient levels (including soil organic matter) did not show statistically significant relationships (P<0.05) with indices of species richness and diversity of vegetation suggesting that the diversity in the vegetation is independent of the nutrient gradients, and plant species richness and diversity may not influence the nutrient dynamics of the habitats sampled. Similar observations have also been reported by Sharma (2004). Further, the intensity of disturbance failed to create edaphic gradient due to free movement of grazing animals and other human activities leading to reduction in ecological diversity in the Sanctuary.

It may be noted that Rebelle (1994), Harper (1977) and Grubb (1977) reported that local disturbance increases the heterogeneity of environment and thereby create a large number of safer sites for herbs. A similar observation has been made in this study in the most disturbed region, Kukas Forest. Aremsto and
Pickett (1985) demonstrated that the small-scale disturbance enhances species coexistence and hence maintains species richness, and successional trends are influenced by disturbance in early stages of succession.

**Composition, Structure and Diversity of Plant Communities across Disturbance Gradient of Landscape**

Vegetation represents the total effect produced by abundance or scarcity of plants. In a floristic study the number and quantity of plants in an area need not be estimated but this is necessary for vegetational analysis. Early botanical studies, worldwide, were purely floristic. The systematic and detailed inventories of flowering plants were initiated by Cooke (1901-08) and Talbot (1909). The first attempts to look at plants collectively in India, were probably those of the forest departments. This was initiated in order to implement their Working Plans. This classification, however, laid emphasis in identifying the exploitation potential of the vegetation (Pascal, 1988). The later work of Champion (1936) was an attempt to classify the vegetation based on climate, physiognomy and edaphic conditions. This preliminary work, which was revised and completed by Champion and Seth (1969), is still used as a reference work in almost all studies on Indian forests. Gaussen (1959) first initiated the notion of series of vegetation, including the various physiognomic stages ranging from the forest to the scattered shrubs encountered in an ecological region. The work of Gaussen (1959) is a major contribution in the field of restoration ecology and the vegetational parameters selected and analyzed in the present study was based on the work undertaken by Gaussen.
Shannon diversity was found to increase with increase in the level of anthropogenic disturbance across the three regions (Table16). The three regions showed statistically significant difference in the Shannon diversity. These results indicate that Kukas Forest is species richer than Nahargarh Biological Park and Jal Mahal Forest, both of which are less disturbed than the Kukas Forest.

The vegetation of Nahargarh Wildlife Sanctuary belongs to tropical dry deciduous forest which is degraded to various stages ranging from thorn forest to scrub. All the three regions of the Sanctuary harbor *Anogeissus pendula* community, associated with *Acacia* and *Prosopis cineraria* (Figures 5, 6, 7 and 8).

The total number of species recorded in the entire sanctuary was 175, out of which the maximum number of species (139) was found in Kukas Forest and least number of species (133) in Jal Mahal forest; the number of species recorded for Kukas forest was closer to that of Nahargarh Biological Park. The number of families to which the species belong varied from 42 to 50. This suggests that taxonomic diversity in the sanctuary is high- a feature of semi arid vegetation.

In all the three regions the dominant family was Poaceae with 31 species, followed by Fabaceae with 22 species. Most of the families were represented by extremely low number of species (Figures 19, 23 and 27) suggesting the prevalence of monotypic families- a characteristic of semiarid vegetation. Most of the species are common to all the three regions suggesting similarity in habitat and contiguity of the habitat; very few species are restricted to specific regions.
(Table 15). For example, species like *Boswellia serrata* and *Acacia catechu* were found in Nahargarh Biological Park only; species like *Aerva lanata* and *Eucalyptus alba* (an exotic plant) were confined to Kukas Forest and *Ailanthus excelsa* and *Ficus religiosa*, both of which are perhaps introduced, were restricted to Jal Mahal forest (Tables 17, 18 and 19).

*Anogeissus pendula* was dominant species in the communities of Nahargarh Biological Park and Jal Mahal forest but it was second dominant species in Kukas Forest. The associated woody species of *Anogeissus* dominated communities were also different among the three regions. For example, the associated species of *Anogeissus* in Nahargarh Biological Park were *Acacia nilotica* and *Ehretia pubescens*; and in Jal Mahal Forest the associates were *Dichrostychus cinerea* and *Wrightia tinctoria*; the associates of Kukas Forest were *Acacia senegal*.

These observations were based on density values of woody species (Tables 17, 18 and 19). The differential densities of woody elements among different regions suggest that sustainability of habitat for multiplication of species differ markedly. For example, all those species having high density values are most favoured by the habitat across the landscape.

The IVI of the species represents the ecological success of species in the habitat. The IVI values of different woody species are markedly different among three regions. For example, the most successful species in Nahargarh Biological Park were *Balanites roxburghii, Dalbergia sissoo, Acacia leucophloea, Ehretia pubescens* and *Prosopis cinererea*; most successful species of Jal Mahal Forest were *Commiphora wightii, Boswellia serrata, Ailanthes excelsa, Holoptelea*
intergrifolia and Wrightia tinctoria; and the most successful species in Kukas Forest was Lannea coromadelica. The results on the composition of plant communities across the habitats suggest that the communities are ecologically differentiated in response to habitat factors.

The relative proportion of trees, shrubs and herbs in the communities analyzed were markedly different among three regions. For example, the ratios of species of trees: shrubs: herbs among Nahargarh Biological Park, Jal Mahal Forest and Kukas Forest suggest that trees were lowest and herbs were predominant in the communities of all the three regions. This indicates that the forests are open with ample insolation reaching to the forest floor. For example, Kukas Forest showed highest herbaceous component (86) with lowest tree component (24) among all the three regions indicating that the community of Kukas Forest is more open than that of Nahargarh Biological Park and Jal Mahal Forest.

The number of tree species also showed marked variation among three regions, with highest number (42) for Nahargarh Biological Park and lowest for Kukas Forest. The number of tree species of Jal Mahal Forest was close to that of Nahargarh Biological Park. DBH values and foliage height diversity, all of which represent structure of the plant community, was also markedly variable among the three regions (Tables 17, 18 and 19). All the three regions showed similar patterns of variation in DBH, with maximum number of trees falling under 20-50 cm DBH interval class and lowest number of trees falling under >200 cm interval class; however that the major difference between Nahargarh Biological Park and Kukas Forest is that highest DBH interval class (>200 cm) was represented by
1834 individuals of tree species in case of Nahargarh Biological Park but in case of Kukas Forest it was represented by 233 individuals of tree species and the value for Jal Mahal Forest was close to that of Nahargarh Biological Park. Similarly, the foliage height diversity also showed marked variation among three regions. For example, the maximum foliage height diversity was found in Nahargarh Biological Park and minimum was recorded for Kukas Forest. These observations on the structure of plant communities also suggest the ecological differentiation of communities across disturbance gradient of the landscape.

The diversity indices- Shannon diversity, Simpson’s diversity index, J and HR showed marked variation among different regions. The species richness is more in Kukas Forest than in Nahargarh Biological Park and Jal Mahal Forest as evident by not only the number of species but also Shannon index values. This can be explained on the basis of high number of herbaceous species that include alien species and native weeds. This also suggests that Kukas Forest is highly disturbed habitat. As expected, Nahargarh Biological Park showed highest species diversity, lowest value of J suggesting high species diversity and heterogeneity in plant communities of Nahargarh Biological Park in contrast to plant communities of Kukas Forest which are characterized by high species richness; low species diversity and low heterogeneity; the Jal Mahal forest communities are close to that of Nahargarh Biological Park with respect to species richness, diversity and evenness (Table 16).

When the diversity indices and tree density and number of species were correlated with the distance of human settlement from forest border, some of the
relationships were positive and others were negative. The distance of human settlement from forest border showed negative and statistically significant ‘r’ values at p<0.05 with number of species, ‘J’ and Shannon diversity indicating that with decrease in distance of human settlement from forest border the species richness and evenness index increased; on the other hand very weak correlation was observed between HR and distance of human settlement from forest border, but the latter’s relationships with tree density and Simpson’s diversity was statistically significant at P<0.05, suggesting that with the increase in distance from human settlement from forest border, there is an increase in tree density and diversity (Figure 18). Similar type of relationships between community characteristics and disturbance regime has been reported by other workers (Daniels, 1989). The influence of disturbance on the species richness and diversity is a much debated concept in ecological literature (Daniels, 1989). It has been reported that non-equilibrium or disturbed condition maintains high diversity (Connell, 1978); intermediate levels of disturbance increases diversity (Connell, 1978; Abugov, 1982); phasing of disturbance increases diversity (Abugov, 1982); periodic disturbances at long intervals increase diversity (Gaedeke and Sommer, 1986).

My data also strongly suggest that the disturbance gradient influences the species richness, diversity and density across the landscapes. It was observed that the density, DBH and IVI of mature trees were low in highly disturbed forest as compared to least disturbed forest; the moderately disturbed forest showed values close to the least disturbed forest; on the other hand the density, DBH and IVI values of exotic invasive species such as Prosopis juliflora increases with
increase in disturbance level. This suggests that the responses of native and alien species to disturbance are markedly different and hence it is important to study species specific responses to disturbance regimes, particularly when invasive species are involved.

It is evident from the above discussion that the composition, structure and diversity of plant communities across uniform edaphic gradient are influenced by disturbance regime. In other words, disturbance is regulator of species composition, structure and diversity of plant communities. Similar observations have been made by other workers (Daniels, 1989; Raman, 2001; Shahbuddin and Kumar, 2006; Jayapal, 1997; Connel, 1978; Shafiq et al, 1997). Infact, my observations demonstrate that, plant communities are evolved through ecological sorting of species across the disturbance gradient of the landscape.

**Avian Community Dynamics and Plant Communities**

Avian community dynamics is one of the well-studied aspects of the ecology of birds. However the relationships between vegetation characteristics and avian community dynamics are not yet clearly understood. It has not been clearly demonstrated about what habitat factors regulate bird diversity. I have attempted to discuss my results on avian community dynamics across the disturbance gradient having plant communities differing in their composition, structure and diversity.

A total of 104 bird species were sighted along the disturbance gradient sampled (Table 20); 43 species were sighted in all the three regions. The number of
species restricted to single localities varied from 4 to 26 with high percent of species specificity for Nahargarh Biological Park and low percent specificity of species for Kukas Forest (Table 20). These observations suggest that the avian community composition in the Sanctuary is variable and is influenced by habitat specific factors which may include disturbance, plant community composition, structure and diversity. Similar observations have been made by other workers. The fact that 104 species were distributed among 42 families (Figure 31), and most of these families were represented by 1 percent to 2 percent of total species indicates taxonomic diversity in the Sanctuary is high- a feature characteristic to biodiversity of semiarid areas.

Although all the three regions showed Corvidae with 12 to 13 percent of the total species as the top most dominant family but the second largest family in all the three regions was Sylviinidae with 8 to 10 percent of the total species (92); however the different regions differ in families having higher number (4 to 7 percent) of the total species. For example, Anatidae (5 percent), Muscicapidae (5 percent) and Passeridae (4 percent) were large families found in Nahargarh Biological Park; in Jal Mahal Forest the third largest family was Passeridae with 8 percent of total species followed by Sturnidae (7 percent); and for Kukas Forest, the third largest family was Cuculidae (7 percent) and Passeridae with 5 percent of total species was the fourth largest family (Figures 35, 40 and 45). It may be noted that in Kukas Forest most of the families were represented by higher number of (2 to 3 percent) of total species but possessed fewer number of species (59) and families (27) as compared to that of Nahargarh Biological Park which showed 92 species and 38 families; Jal Mahal forest also showed higher
number of species (62) and families (29) than Kukas Forest. These patterns of
distribution of species and dominant families might be due to multiple ecological
gradients, including climate, plant community characters and microclimatic
conditions rather than disturbance gradient alone. This is further evident by the
patterns of distribution of resident, migratory and bird species endemic to Indian
subcontinent (Figures 36, 41 and 46).

With respect to conservation status of birds sighted, all the species (except for
two species) sighted in all the three regions fall under IUCN threatened category
of Least Concern. Two critically endangered bird species (*Sarcogyps calvus* and
*Gyps bengalensis*) were sighted in Nahargarh Biological Park and one species
(*Sarcogyps calvus*) of Jal Mahal Forest was also endangered; both the species
were not sighted in Kukas Forest suggesting their local extinction due to
disturbance.

Observations together with the patterns of distribution of species and families
across three landscapes analyzed suggest that the avian communities are mostly
composed of generalists with wide ecological amplitude.

The species richness and diversity profiles are markedly different among three
regions (Table 21). For example, the Shannon diversity index was high for Jal
Mahal Forest as compared to that of other regions, but Simpson’s diversity index
was highest for Kukas Forest among all the three regions; HR and number of
species were highest for Nahargarh Biological Park among all the three regions.
These results suggests that: (i) Kukas Forest has an avian community which is
more diversified and heterogeneous than those of Nahargarh Biological Park and Jal Mahal Forest inspite of low number of species; (ii) the avian community of Nahargarh Biological Park has more number of species than those of Jal Mahal Forest and Kukas Forest; and (iii) the avian community of Jal Mahal Forest is species rich, diversified and heterogeneous. These patterns of variation in avian communities among three habitats having different levels of disturbance can be explained on the basis that several factors such climate, vegetation characteristics and disturbance might be influencing observed avian community dynamics across the habitats.

The species richness and diversity indices were plotted against distance from human settlement from forest border; the ‘r’ values were negative and statistically nonsignificant at P<0.05 for combinations involving Shannon Diversity and J with the distance human settlement from forest border; the ‘r’ values for all other combinations were statistically significant at P<0.05 and were positive except for the combination of Simpson’s diversity with the distance of human settlement from forest borders, for which the ‘r’ value was negative (Figure 34). These observations suggest that species number, diversity and evenness are influenced by disturbance gradient across the landscape. The number of species and evenness increased with increase in distance. The disturbance might be influencing avian community dynamics through changes in plant communities and microclimate across the landscape.

Climate has been shown to play a significant role in determining the avifaunal assemblage in any area (Daniels, 1989; Holmgren et al, 2001; Vandermeer et al,
2000; Kohler et al 2001). My studies on the seasonal and annual variations in bird species across the habitats of three regions extend support to the observations made by other workers on the role of climate on the dynamics of avian communities. With the onset of rainfall, a seasonal increase in the avifauna was recorded for all the three regions (Figure 38, 43 and 48). This can be explained on the basis of the fact that during the monsoon months the high moisture and lush green new growth of foliage enable to support abundant larvae and adult insects which form the food base for birds and hence the increase in abundance and number of bird species during monsoon.

The decline in the number of species and their abundance during post monsoon months and also during winter months might be essentially due to limitation of insect food due to leafless condition of vegetation and absence of grasses; the slight increase in the number of species and their abundance during summer months might be due to appearance of new foliage, flowers and fruits, all of which not only enhance insect food base but also serve as food for birds. Infact during March-June, some perennial grasses also produce new growth and grain which serve as food for birds. Similar observations have also been made by other workers (Daniels 1989; Kohler et al 2001). In other words the phenology of vegetation determines the food base of birds in different seasons.

Seasonal patterns of variation were observed in number of bird species (Figure 38, 43 and 48) and their abundance among all the three regions and the differences in the number of species sighted in specific seasons among three regions were marginal. These observations suggest that the macroclimate is
essentially similar across the landscapes, but local micro-climatic conditions, vegetation structure and phenology, and disturbance factors of the region might be responsible for region specific seasonal patterns of number of bird species observed across the landscape.

Besides seasonal patterns, the bird species also showed marked annual variations, the patterns of which are similar across the landscapes; region specific annual variations were also observed. For example, in the year 2003 the number of bird species sighting was 21 at Nahargarh Biological Park during monsoon but in 2004 it was 15; similar patterns were observed at other regions. This can be explained on the basis of annual variation in weather patterns, particularly the precipitation level and temperature regime both of which vary markedly from year to year.

In all three regions, resident bird species were predominant (60 to 80 percent), although highest number (80 percent) of resident bird were observed in highly disturbed habitat- Kukas Forest; the migratory species were relatively low in proportion (12 to 16 percent) to resident birds; similarly the bird species endemic to Indian subcontinent was low (6 to 9 percent). These observations suggest that most of the bird species in the community are generalists. It is difficult to explain the low proportion of migratory birds in the Sanctuary. It might be due to disturbance and also due to lack of suitable habitats. Geographical isolation of the area might also be another reason for low proportion of endemic bird species.
Two critically endangered species (*Sarcogyps calvus* and *Gyps bengalensis*) were recorded from the sanctuary during the present study (Table 20). The major threat to both the species is the disturbance. This is evident from the facts that with the increase in level of disturbance, a reduction in the distribution range of these two critically endangered species was observed (Figures 37, 42 and 47). Both these species were sighted rarely by me from Nahargarh Biological Park (which is least disturbed), and out of two species, only one species (*Sarcogyps calvus*) was observed very rarely in Jal Mahal Forest, which is moderately disturbed; both species were absent in Kukas Forest which is highly disturbed. Similar observations have been reported earlier (Rotenberry, 1985). Rare and large bodied birds have been reported to decline disproportionately in abundance in altered habitats (Raman, 2001). Infact, the two endangered birds in the Sanctuary are large bodied vultures, and their present conservation status is due to decline in available habitat area as well as niche-resources in altered habitats. Besides rarity, other factors such as foraging strata and feeding guilds have also been reported to affect the persistence of species as the level of disturbance increases (Raman, 2001).

Keeping in view of the above mentioned aspects, I have discussed my results on the variation in the number of bird species among different guilds in the following pages. The bird species sighted in the Sanctuary can be grouped into 16 feeding guilds based on their food habits. All the 16 feeding guilds were observed in Nahargarh Biological Park but only 13 and 12 guilds were recorded in Jal Mahal and Kukas Forests, respectively (Figures 39, 44 and 49). The feeding guilds absent in Jal Mahal Forest and Kukas Forest were: Herbivore, Granivore-
Carnivore and Frugivore; the Scavenger feeding guild was also absent in Kukas Forest, besides the three earlier mentioned guilds. These observations suggest that specific fruit bearing foliage and grain/seed bearing plant species, specific animal species that serve as prey and also specific dead insects and small animals might be absent in Jal Mahal Forest and Kukas Forest. The plant and animal species, on which the birds of these feeding guilds depend, might have been locally extinct due to disturbance or the birds might have switched over to other dietary habits in the absence of their preferred diets.

The pattern of variation in the number of bird species in different dominant feeding guilds is similar among different regions. For example, the top 5 feeding guilds- Insectivore, Insectivore-Nectarivore, Omnivore, Granivore and Carnivore were common to all three regions but their relative position differ within the top 5 ranks, except for the topmost rank i.e. insectivore which is common to all the three regions. For example, in Nahargarh Biological Park, the second position was occupied by Insectivore-Nectarivore feeding guild, but it was replaced by omnivore and granivore in Jal Mahal Forest and Kukas Forest, respectively. In other words, there is a marked diversity in food base for bird species among three regions which might be related to disturbance regime. The number of birds belonging to each guild markedly declined in relation to level of disturbance of the area. For example, the highly disturbed area Kukas Forest showed marked decline in number of species in the feeding guilds as compared to that of Nahargarh Biological Park and Jal Mahal Forest; Jal Mahal Forest is also moderately disturbed and there is a decline in the number of birds in the guilds as compared to that of Nahargarh Biological Park. These results suggest that the
size of food web of the birds is variable among the three regions, and the food web size decreases with increase in disturbance.

A comparison of the number of bird species belonging to insectivore across the three regions shows that there is a decline in the size of the most dominant feeding guild with increase in disturbance, with lowest number of bird species recorded for Kukas Forest and highest for Nahargarh Biological Park. Similar decline in the terrestrial and understory insectivorous birds has been reported by Raman (2001) and Jones (1989). It is not known whether it is the paucity of vegetation (serving as protective cover from predators and nesting or foraging substrate) itself or its indirect negative effects on arthropod availability, or both might be associated with the decline in insectivorous birds in disturbed habitats. Low tree density (due to increasing levels of anthropogenic disturbance) has been reported to have negative consequences on the populations of bark-surface feeders like woodpeckers (John, 1989; Thiollay, 1995; Raman et al, 1998).

Insectivorous birds are of special concern in conservation policy because of their sensitivity to forest alteration and fragmentation at many places (Johns, 1991; Canaday, 1997; Lohr et al, 2002; Raman and Sukumar, 2002; Sekercioglu et al, 2002). Insectivorous birds require specific canopy architecture and microclimatic conditions that are available only in native, undisturbed forests; and these requirements are altered by activities such as logging, conversion to plantations, fuelwood extraction and livestock grazing in disturbed areas leading to decline in the size of insectivore feeding guild (Shahabuddin and Kumar, 2006).
The omnivorous guild was the second and third dominant guild in Jal Mahal Forest and Kukas Forests, respectively. In other words, omnivorous birds are most abundant in disturbed areas and close to human settlements than in relatively undisturbed and interior forest areas. The omnivorous birds are better adapted in the disturbed areas because of their wider dietary flexibility. Similar trend has been reported by earlier workers also (May, 1982). Omnivores are generalists and are more abundant in the open canopy conditions, near human settlements, in association with other forest species. Restrepo and Gomez (1998) also made similar observations. These habitat generalists are less sensitive to habitat changes than the forest interior birds and replace the sensitive ones (Telleria and Santos, 1995; Chettri et al, 2001; Easton and Martin, 1998; Francl and Schnell, 2000). Species sensitive to disturbance by humans have been reported to avoid areas or occur in reduced abundances where human activity is common (Miller et al, 1998).

The populations of canopy birds that include insectivores, frugivores and nectarivores-insectivores showed a declining trend with increasing levels of anthropogenic disturbance. Similar pattern of distribution of canopy birds has also been reported by many other workers (Terborgh and Winter, 1980; Bowman et al, 1990; Thoillay, 1995; Raman et al, 1998). This can be explained on the basis that tree density decreased with increase in disturbance (Table 16) and this in turn led to decrease in canopy cover leading to decline in the canopy birds in disturbed habitat.
Bird species diversity (Shannon) was the highest in Jal Mahal Forest (which is characterized by intermediate level of disturbance) (Table 21). This might be due to the presence of more openings that enable greater resource exploitation in areas with intermediate levels of disturbance. Similar results have also been reported by earlier workers (Daniels, 1989; Javed, 1996 and Shafiq et al, 1997).

**Relationships between Avian Community Diversity and Plant Community Diversity**

Plants and birds exemplify the mutualistic interaction and are known to generate coevolution of plant and bird species. Bird species depends upon plants for its food, directly or indirectly, nesting and protection, and the plant species in turn are benefitted from the birds which bring out pollination and dispersal- the two critical processes essential for plant survival and evolution. These mutualistic interactions are often highly species specific. Substantial work has been carried out on these aspects. However, the role of plant communities in avian community dynamics is debatable.

Keeping in view of the above mentioned aspects, I have attempted to discuss my results on correlative studies involving bird diversity and richness in four different seasons and plant community characteristics such as plant diversity, foliage height diversity, tree density and number of plant species for three different regions.

The statistically significant correlations (at P<0.05) of bird species diversity and richness with plant community characteristics such as plant diversity and foliage
height diversity were observed in all the seasons for Nahargarh Biological Park (region with minimum anthropogenic disturbance) and in Jal Mahal (region with intermediate level of anthropogenic disturbance) except in some combinations involving tree density, but no such correlations were observed for Kukas forest except for the combination of bird diversity in summer with foliage height diversity (Tables 22, 23 and 24). Similar type of relationships has been reported by other workers (Thoillay, 1990; Connel, 1978; Jones et al, 2003).

Statistically significant relationships (at P<0.05) of bird species diversity and number of bird species in all seasons (except in monsoon season in case of bird diversity) with the number of plant species were observed for Nahargarh Biological Park, and for Jal Mahal Forest (except for combinations in winter season). These observations also extend support that intermediate disturbance promote higher plant and bird diversity. I did not find any relationship of tree density with the bird diversity and richness in all seasons (except in summer and spring) for Nahargarh Biological Park; similar relationships were observed for Jal Mahal Forest and Kukas Forest. This suggests that tree density might not be a major determinant for bird diversity and richness. Tree density, age and height (which are determined by the level of anthropogenic disturbance) have been shown to be the determinants of bird community composition in the area (Laiola, 2003). Areas supporting lower densities of trees (Kukas forest in this study) are found to be less attractive for insectivorous, frugivorous and insectivorous-nectarivorous birds. This has also been reported by Laiola (2003) as well.
Tree height is positively correlated with tree volume and together with density, determines the productivity of forest areas; all the three variables together might have a role in determining the bird community composition of the area. Santos et al (2002) have reported that vegetation structure influences the bird diversity through heterogeneity. They have further emphasized that small forest patches have much poorer bird habitats. Kukas forest, the region with maximum disturbance, has degraded patches of vegetation with crooked trees having poor cover and has lower bird diversity as compared to that of Nahargarh Biological Park and Jal Mahal forest, which have higher bird diversity and higher plant diversity (Tables 16 and 21 and Figures 5, 6, 7 and 8.). This is substantiated by the fact that no statistically significant relationships (at P<0.05) of bird diversity and number of birds with plant diversity and foliage height diversity was observed (Table 24) for Kukas Forest. The reduction in heterogeneity of forest might be due to anthropogenic disturbances. Similar relationships have been reported earlier also by Freemark and Kirk (2001).

Greater anthropogenic disturbance results in lesser heterogeneity of vegetation. The strong correlations of bird diversity and number of bird species with plant species diversity (Tables 22, 23 and 24) substantiate that heterogeneity enhances bird diversity and richness. This also implies that diversity in vegetation structure is required to maintain higher bird species diversity and the biotic integrity. Forests with greater heterogeneity in the structure and composition have been reported to have more avifaunal species (Recher, 1969; Willson, 1974; James and Wamer, 1982; Freemark and Merriam, 1986; Easton and Martin, 1998). Nahargarh Biological Park (region with minimal level of
anthropogenic disturbance) harbours mature deciduous forest with maximum woody plant species and higher heterogeneity and hence supports the highest number of bird species and high diversity. Similar observations have been made by James and Wamer (1982).

Foliage height diversity and bird diversity in all the seasons were strongly correlated and ‘r’ values were statistically significant (at P<0.05) for Nahargarh Biological Park and for Jal Mahal the ‘r’ values were significant at P<0.05 in all seasons; and for Kukas Forest, the statistically significant ‘r’ value was observed only in one season (Tables 22, 23 and 24). These observations suggest that disturbance might be affecting foliage height diversity which in turn impacts bird diversity adversely. This is clearly evident by the pattern of relationships observed between bird diversity and number of bird species in all seasons with foliage height diversity for Kukas Forest, for which all the ‘r’ values were statistically nonsignificant at P<0.05. These observations demonstrate that disturbance contributes to decline in bird diversity and richness indirectly by changing the tree foliage height diversity. Foliage height diversity is actually a measure of the canopy height, foliage volume and the evenness of distribution in the height categories (James and Wamer, 1982). In other words, with increase in the level of disturbance, foliage height diversity and canopy cover decrease. A similar observation has been reported by Francl and Schnell (2000).

The density of Prosopis juliflora was the highest in Kukas forest (Tables 17, 18 and 19) which also showed the lowest bird species diversity (Table 21). Such relationship between invasive species and bird species diversity has been
reported by earlier workers also (Dean et al, 2001). This can be explained on the basis that reduction in food availability (particularly fleshy fruits and invertebrates) in *Prosopis juliflora* dominated woodlands might have led to decrease in bird diversity. Further, the branch height and angle of *Prosopis juliflora* are unsuitable for most perch hunters, and hence resulting in an impoverishment of avifauna in *Prosopis juliflora* dominated woodlands.

Although bird species composition changes significantly because of disturbance, overall species richness and bird abundance were not significantly different across the disturbance gradient. This is because although some species show higher densities in the disturbed areas, disturbance alters the vegetation structure leading to decline in several bird species. Similar results have been reported earlier by Shahbuddin and Kumar (2006). Disturbance thus, may result in greater landscape level bird diversity (than if there were no human use at all) because of the creation of habitat patches that can support different assemblages of birds. This is amply evident in my study (Table 21). A similar observation has also been reported by Shahbuddin and Kumar (2006).

To sum up, disturbance effects plant community composition, structure and diversity which in turn influence avian community composition, structure and diversity. In other words biotic integrity is altered by disturbance leading to overall loss of biodiversity and resilience of the ecosystems, although the number of bird species and diversity may increase in disturbed habitats. It may be noted that there is ample evidence from my studies that the observed patterns of variations in plant and bird communities are perhaps the outcome of ecological
sorting of species across the disturbance gradient of the landscape leading to evolution of biotic communities.

**Territory Size and Disturbance**

Type A territorial birds are extremely sensitive to their territory sizes. It has been suggested that anthropogenic mediated activities do influence the territory size of birds. To understand the effect of anthropogenic disturbances on the territory size of a type A territorial bird, mapping of the territory size of Magpie Robin was done across the disturbance gradient. Territory size increased with the increase in levels of anthropogenic disturbance (Table 25). With increase in the level of disturbance, the degradation of forests also increased. This is evident from the fact that tree density declined with increase in anthropogenic disturbance across the three regions (Table 16); decline in tree density leads to a decline in the number of insects and this in turn results in reduction in food base (insects). Consequently, the insectivorous birds have to cover larger distances in search of food and hence contributing to increase in their territory size.

Territory spot mapping method has been widely used in temperate region for mapping territory of territorial birds during their breeding season (Verner, 1985). Ornithologists have also employed this method for territorial birds in tropical areas (Terborgh et al, 1990; Thiollay, 1994; Robinson et al, 2000). My studies on the territory size of Magpie Robin across the disturbance clearly demonstrates that spot mapping method can be applied successfully to map the territory size of territorial birds of semi-arid regions.
However, there are limitations in the application of spot mapping in my present study. Firstly, territoriality needs to be confirmed through use of marked individuals (through mist-netting and colour ringing). This was not done by me, and therefore, my study represents a preliminary attempt to document territoriality. Second, the shape and size of the plots chosen for this study were dictated by logistics, and were not ideal for mapping. A larger plot is required for mapping some of the larger, wide-ranging birds (e.g. woodpeckers, hornbills). A third factor is the lack of information on seasonal changes in territoriality and social organization. More research studies are needed to overcome the limitations of spot mapping so that the method can be successfully employed to study and monitor bird populations throughout the Aravallis.

Where time and resources are available, territory spot-mapping should be used as the method of choice by ornithologists for obtaining information on density, territory sizes and social organization and behavior; mapping can also yield insights on the area requirements of birds of Aravallis and spatial patterns of plot occupancy or diversity (Terborgh et al, 1990), intra- and inter-specific territoriality (Robinson and Terborgh, 1995) and bird distribution in relation to resources or habitat. The major drawback of territory mapping is the greater time and effort needed; for a given effort it may be possible to survey fewer areas with mapping than with other methods such as transects.

**Predation of Nests and Biotic Factors**

Predation of nests is critical factor in deciding the abundance of bird species and regulates avian community dynamics. A number of biotic factors are known to
contribute to the predation of nests (Maina and Jackson 2003; Crabtree et al 1989; Paton 1994; Mac Ivor et al 1990). I have investigated the effects of disturbance, colour of eggs and edge effects using artificial nests and eggs. The results are discussed in the following pages, keeping in view of the role of nest predation in avian community dynamics.

**Disturbance and Nest Predation:** Anthropogenic mediated disturbances result in changes in the vegetation structure, reduction of cover (due to clearing of forested areas), and reduction in plant density and diversity. Increased human activity also results in the enhanced trampling of vegetation of the area. Excessive human pressures on forests have been resulting in fragmentation of habitats. Fragmentation of habitats can influence predation rates through the phenomena of mesopredator release (Soule et al 1988, Maina and Jackson 2003).

Nests in areas with poor vegetation cover are more susceptible to predators (Janes 1985, Sullivan and Dinsmore 1990). Several workers reported positive relationships between vegetation cover and nesting success (Odin 1957, Choate 1967, Chesness et al 1968, Dirernychuk and Boag 1972, Jones and Hungerford 1972 and Crabtree et al 1989). Tall and dense vegetation establishes visual and scent barriers between predators and nests (Schrank 1972, Duebbert and Kantrud 1974, Duebbert and Lokemoen 1976, Livezey 1981, Hines and Mitchell 1983 and Crabtree et al 1989). Similar results have been reported by Jokimaki and Huhta (2000) in towns, wherein the predation rate was higher in managed parks than in unmanaged parks. They pointed out that the differences observed
between managed and unmanaged parks by them was due to dense vegetation in unmanaged parks as compared to that of managed parks.

Increased human visitation to areas having nests also enhances nest predation (Esles and Grand 1993). Increased human activity may impact the vegetation near the nest and this may act as important proximate cue for predators leading to increased predation.

In my studies, I found that Kukas Forest showed highest nest predation and lowest was observed for Nahargarh Biological Park suggesting that highly disturbed areas are prone to enhanced predation. This is further confirmed by the fact that the Delhi Ridge, which is highly fragmented and encircled by the city and dominated by *Prosopis juliflora* and primates showed maximum nest predation (Figure 50). Further, statistically significant relationship (at P<0.05) between number of nests attacked and distance of human settlement from the forest (reflected by the regions in which the nests were placed) (Figure 50) strongly suggests that disturbance increases predation. The high predation of nests in Kukas Forest is due to inadequate vegetation cover and a poorly developed field layer. A low and poor vegetation cover increases the visibility of nests to visually searching avian-nest predators. The relatively low nest predation in Nahargarh Biological Park is due to its taller and dense vegetation cover that ensures greater concealment of nests. Similar observations have been made by Seitz and Zegers (1993). It has been suggested that predators can move and visually locate nests with ease in relatively sparsely vegetated areas as compared to areas with denser vegetation.
Colour of Eggs and Nest Predation: Eggs in open-cup nests (as opposed to cavity nests) are exposed to visually searching predators during laying and pauses during incubation, which together represent a significant part of the entire nesting cycle (Weidinger 2001). Consequently, I conducted experiments to understand the effect of colour of eggs on nest predation. The results on the effect of colour of eggs on nest predation did not show marked difference in nest predation rates between white and blue coloured eggs (Figures 52 and 53) suggesting that colour of the egg does not affect predation rates in a typical Aravalli forest ecosystem (Figure 51). Similar results have been reported from different ecosystems by other workers (Yahner and Delong 1992, Janzen 1978, Slagsvold 1980, Salonen and Penttinen 1988, Major and Kendal 1996, Greenberg et al 2002).


Visually oriented predators may locate nests by using cues other than egg colour like by observing parental behaviour (Martin et al 2000). Nest predation is traditionally assumed to constrain the brightness of plumage of incubating birds (Wallace 1889, Martin and Badyaey 1996). However, several studies have shown
that bright plumage (Stutchbury and Howlett 1995) or artificial bright colour at the nest (Haskell 1996, Miller 1999) did not increase the risk of predation on elevated nests. Alternatively, predators may search directly for conspicuous nests (Moller 1990, Cresswell 1997). Thus, nests and / or adults and not eggs may be detected first by a predator.

**Edge effect and nest predation:** Habitat fragmentation is one of the main causes of the recent impoverishment of biodiversity (Vitousek et al 1997, Batary and Baldi 2003, Didham et al 2012). Habitat fragmentation - the conversion of a formerly continuous habitat into small, isolated remnant patches, results in the loss of wildlife habitat and degradation of landscape. Edges may alter the distribution, abundance and behaviour of organisms, and this phenomena is termed as the edge effect (Murci 1995).

Edges have been reported to adversely effect a wide range of avian species by increasing depredation and parasitism rates of nests (Paton 1994).

Fragmentation also results in the phenomena of ‘mesopredator release’ at the edge (Soule et al 1988, Maina and Jackson 2003). The removal of the top predator in the fragments results in the increase in the number as well as the activity level of small sized predators (Terborgh 1988) and thereby increasing the predation levels at the edge.

Edges have been reported to provide perches with a clear view of the surrounding habitat, and hence results in greater levels of predation (Rath and
Reesey 1988, Moller 1989). Infact, edge effect or higher nest depredation at the edges is the most frequently cited explanation for population declines of birds in fragmented landscapes (Paton 1994).

Keeping these aspects in view, I have discussed my results on the effects of edge on nest predation in the following pages. The rate of nest predation was higher (91.49%) at fragment edges as compared to the interiors of forests (74.51%). The rate of nest predation differed significantly between the nests placed at the forest edge and those placed at the interior of the forest ($\chi^2 = 4.642$, d.f. = 1, $p<0.05$). These observations indicate the prevalence of edge effect in Nahargarh Wildlife Sanctuary. This is consistent with a large body of evidence obtained from various forest ecosystems using artificial nests.

However, a few studies have failed to find increased predation rates on the edge as well (Yahner and Wright 1985, Angelstam 1986, Lahti 2001). Yahner and Wright (1985) and Angelstam (1986) studied small fragments where the centre of the habitat was within 50m of the edge. Habitat in such fragments may be entirely edge habitat, and hence no difference in predation rates between edge and interior of the habitat was reported. Lahiti (2001) evaluated 55 studies relating to the effects of egde on nest predation and found no support for increased nest predation rates near habitat edges. He, however, did not use any statistics, and hence his observations might be biased.

**Distance from edge and nest predation:** Edge has been shown by many workers as a major factor that influences nest predation. My observations (see pages 134-136) extend support to the view that edge effect regulates nest predation.
The effects of distance from edge on the nest predation have not yet been investigated, except for few studies (Johnson and Temple 1990, Andren and Angelstam 1988). In the present studies, nests were placed at different distance class intervals from the edge primarily to find out the extent of spread of the edge effect from the edge. The results obtained in this study are discussed below.

The edge effect on nest predation was high within 50 m of the edge and beyond this the rate of nest predation decreased with increase in distance from the edge. This is evident from the statistically significant differences (at P<0.05) in nest predation between distance interval classes (Figures 56 and 57).

As has been pointed out elsewhere, edge effect has impact on avian populations. However, many investigators demonstrated a greater bird density at the edge (margin of two habitats) than in the interior of large tracts of uniform vegetation (Lay 1938, Good and Dambach 1943, Edenburn 1947, Johnston 1970, Gates and Gysel 1978). The intensity of edge effect decreases with the increase in distance towards the interior of forest as well as away from the edge (Andren and Angelstam 1988, Johnson and Temple 1990). Paton (1994) demonstrated that the increase in predation along edges is limited to the first 50 m from the edge.

Investigations on abiotic and vegetational factors revealed that edge effects occur less than 50 m towards the interior of a forest stand (Ranney et 1981, Kapos 1989, Laurance and Yensen 1991).
The inverse (negative) relationships of bird activity with the distance from the edge into the forest stand could be due to decrease in perch sites inside the forest stand (Ratti and Reese 1988, Moller 1989, Paton 1994). This is also amply demonstrated by the studies conducted by Avery et al (1989). No biological evidence for edge effects was found when the nests were placed 100 m or more away from the edge. Avian predators use woods for perch sites to locate habitat and the distance of 100m might have been too far to find any hidden artificial nest (Paton 1994).

Predator activity has also been reported to be maximum at the edge and decreases with the increasing proximity to the forest stand. Activity of avian predators as well as mammalian predators like red squirrels, shrews, weasels and raccoons have been shown to be more in the vicinity of the edge and their activity has been shown to decrease towards the forest interior (Bider 1968, Bider et al 1968, Gates and Gysel 1978).

Nesting success (measured in terms of nest hatching success) has been shown to have a positive relationship with distance from the edge (Gates and Gysel 1978, Chasko and Gates 1982). Nest predation rates showed statistically significant (at P<0.05) negative relationship with the distance from the edge.

However, the trend of increase in nest predation rates within 50 m from an edge has also been challenged by Boag et al (1984) and Yahner and Wright (1985), who conducted studies by placing nests not far enough from the edge. For example, Boag et al (1984) compared predation rates between nests placed at

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less than 15 m and those placed at greater than 20 m from a trail. Yahner and Wright (1985) placed nests at 0 m and 50 m from the edge of 1 ha fragments. In both these studies nests were not placed far enough away from an edge. Paton (1994) pointed out that these artificial nests were potentially located within a relatively homogenous band of predation pressure and predation rates might have declined beyond the sampled area.

My observations on the nest predation rates in relation to the distance away from the edge strongly support the empirical evidence provided by earlier studies that the effects of edge on nest predation occur within 50 m of an edge. However, more focused research on the nest dynamics within 100-200 m of the ecotone between forest and unforested habitat and also at smaller distance increments from the edge may provide further insight on the role of edge effect on avian population dynamics.

Artificial nests have been used extensively to study nest predation. However, there are number of limitations associated with their use. Some of the earlier studies indicated that predation rates on artificial nests were comparable to that of real nests (Gottfried and Thompson 1978); in some studies the predation rates on artificial nests were markedly higher than on real nests (Mac Ivor et 1990, Reistma 1992); and in still other studies (George 1987, Willebrand and Marcstrom 1988, Roper 1992) the predation rates on artificial nests were lower than that of real nests.
One major difference between artificial and natural nests is that there are no parent birds at artificial nests. Parent birds may defend their nests from predators (Mac Ivor et al 1990) or may attract the attention of predators by their movements, smell or sound at the nest. A combination of these factors might be influencing the rate of predation at real nests and absence of these factors at artificial nests might be changing nest success as compared to natural nests. Nevertheless, artificial nests reveal the class of predators and test such differences as fragment size and edge.

The high loss of artificial nests to bird predators might also be due to the result of birds cueing to human activity in the siting of nests, particularly if they associate people with food. However, these bird predators may equally be cued to natural nests by the parent birds.

Since artificial nests contain eggs only, it is not possible to study other predators responsible for the depredation of nestlings.

Another shortcoming with the use of artificial nests is that they can not be used to evaluate levels of nest parasitism.

Baited artificial nests and actual bird nests obviously differ in several ways such as appearance, presence or absence of adult birds, type of odor, egg size, specific nest location and possibly other features. Artificial nests in this study were wired to trifurcate branches. In most cases these nests appear to be more conspicuous than the actual nests. Even so, a human passerby would not notice
any of the artificial nests without intentionally searching for them. To the predators, increased visibility may be offset by the lack of adult activity to and from the nest, but it is difficult to say to what degree these two factors balance each other.

Nevertheless, there are obvious advantages in using artificial nests. In fact many of the seminal studies on the effects of habitat fragmentation on reproductive success were discovered through the use of artificial nests.

Results from artificial nests should not be used to measure actual rates of predation or to suggest how reproductive success varies with landscape and habitat features in regions where nest parasitism is high. Nor should they be used to detect trends in rates of predation across sites if the composition of the predator community differs among sites.