Avian communities are the characteristics and properties of assemblage of species population (Koromondy 1989) or the group of populations that occur together (Ricklefs 1990). Major goals of avian community ecology are to identify recurrent pattern of species composition, guild structures, diversity and other parameters among co-occurring species and to understand the factors promoting those patterns (Wiens and Rotenberry 1980). Being ecologically diverse and sensitive to various kinds of perturbations, avian community acts as a better predictor of the quality and health of the habitat than single species (Javed 1997).

In the last few decades avian community studies have received its due attention. This trend was boosted after the publication of MacArthur and MacArthur’s paper on bird species diversity in 1961. This study led to the initiation of various studies aimed at investigating the relationship between bird species diversity and structural diversity of the habitat. The outcome of these developments was the generation of new ideas, critical evaluation of the theories and models and even formulation of new theories.

The beginning of community ecological studies can be traced back to Clement (1916). His conclusions that “communities are discrete assemblages which are closely integrated” laid the foundation of community ecology. However, except few studies by Lack (1954), Kendeigh (1934), this branch did not receive much attention of biologists till MacArthur’s work in early 60s. MacArthur and MacArthur (1961) through their paper on bird species diversity established the view that bird species diversity is a function of foliage height diversity. This seminal work infact revolutionised the thinking on the subject and a series of studies on the same lines followed.

Pattern in avian communities are based on some deterministic processes - a cause and effect relationship (MacArthur and Wilson 1967). Cody and Diamond (1975) argued that competition plays an important role in the community organization and is responsible for the structuring of species along a resource – utilization axis.

Food is an important limiting resource (Lack 1954, Cody 1968). Holmes et al. (1979) and Terbogh (1985) proposed that communities should be structured on the basis of how food is partitioned and that synoptic species should differ in physical or behavioural characteristics resulting in different food utilizations. Studies of MacArthur and MacArthur (1961), MacArthur and Pianka (1966) James (1971) and Erdelen (1984) revealed the relationship between bird species diversity and foliage height. However, some studies have failed to establish the same relationship in the tropical forest habitats (Pearson 1982, Wiens 1989).

Existing theories of community organization have ascribed different roles to both biotic (Pianka 1973, Diamond 1974) and abiotic factors (Wiens and Rotenberry 1980, Dunson and Trans 1991). Bird species diversity have been found to be the function of certain
features of habitat like total foliage volume (Karr and Roth 1971), Vegetation cover (Wilson 1974), trophic level (Airola and Barett 1985), foraging strategies (Holmes and Robinson 1981), canopy cover (James and Warner 1982, Wiens and Rotenberry 1981), microhabitat like tree fall opening in forest (Terbogh et al. 1990) or rocky outcrops in shrub steppe habitat (Wiens and Rotenberry 1981). Along the whole vegetation gradient most bird species tend to be related to structural variables, though some birds may be associated more with particular plant species (Rotenberry 1985, Bersier and Mayers 1994, Estades 1997).

Cornell and Orias (1964) argued that the extent of diversity of a community depends on the rate of energy flow through the food web which in turn is influenced by the stability of the environment because less energy will be consumed for regulation of the environment. Over the years communities tend to evolve to have greater diversity (Fisher 1960, Simpson 1964).

Bird species diversity and richness is also related to the size and extent of vegetation i.e. patchiness (Beals 1964). Avian communities are also susceptible and responsive to changes in the land use pattern (Daniels et al. 1990). Habitat fragmentation as a consequence of clearance of large tracts of forest leads to changes in the avifaunal structure and composition. Various environmental factors also affect the communities such as rainfall, drought (MacArthur 1964, Holmes et al. 1986) and the climatic instability, which limits the opportunity for the niche diversification (Weins 1991).

Bird communities are used as indicators to efficient monitoring of ecosystems (Canterbury et al. 2000). Birds are considered to be a good indicator of environmental quality and are
frequently being used to monitor environmental and ecosystem health (Jarvinen and Vesaunen 1979). By virtue of conspicuous nature they are easily researched more importantly with agro issues, their pattern of behavior, distribution and demography track closely onto the spatial and temporal scales of agricultural changes (Bradbury et al. 2000, Ormerod and Watkinson 2000). Bird assemblages based on species composition, abundance, richness and diversity along with other attributes as rarity and endemism are frequently used for ornithological evaluations and assignment of conservation value to sites (Fuller 1980, Daniels et al. 1990). As a consequence of habitat destruction many species with narrow habitat ranges have either become locally extinct or show a decline (Arnold and Weeldenburg 1990).

In India many studies have been conducted in different habitats on avian community. Gaston 1978, Price 1979, Sugantham 1982, Ali and Vijayan 1986, Beehler et al. 1987, Joshua and Johnsinh 1988, Katti 1989, Daniels et al. 1991, Daniels et al. 1992, Price and Jamadar 1990, Rai 1991, Sundaramoorthy 1991, Johnsinh and Joshua 1994, and Natrajan and Rahmani 1996, Javed 1997 etc. However, none of the studies was carried out in fragile and threatened ecosystems of Garhwal Himalayas and Pathri Rao taking watershed as a unit of study. The present study was carried out with the following objectives:

✓ To prepare an inventory of the birds of Phakot and Pathri Rao Watershed Areas.
✓ To evaluate bird species diversity and bird species richness over a period of time.
✓ To investigate the bird community structure in Phakot and Pathri Rao Watershed Areas.
2. Methods and Methodology

2.1 Classification of Phakot and Pathri Rao in different habitat categories

The habitats in PWA were classified based on the dominant species present in the habitat. Oak, pine, sal and mixed bakli were dominated by *Quercus leucotriphora*, *Pinus roxburgii*, *Shorea robusta* and *Anogeissus latifolia* respectively. Miscellaneous forest consisted of mix of *Quercus leucotriphora*, *Bauhinia spp*, *Eupatorium adenophorum* and *Rhus parviflora*. In Pathri Rao dry deciduous forest was classified based on the tree cover density using IKNOS data. Deciduous forest (L) was defined as forest with a cover up to 40%. Deciduous forest (M) had a cover density between 40 to 70% and deciduous forest (D) had forest cover density more than 70%. Riverine included forest besides the river and sand dunes whereas plantation included mango orchards, and *eucalyptus* spp.

2.2 Species listing method

Species listing method was employed and 15 bird species observed were taken as cutoff in each list. Thus each list consisted of 15 species of birds which may or may not reoccur in subsequent lists. A total of 15 such lists were found enough for the survey (Poulsen et al. 1997a)

2.3 Distance sampling for comparing bird density

The bird communities were sampled using the fixed radii (20m) Point Count method (Reynolds et al. 1980). The sampling points were taken through stratified random method. A distance of approximately 250 meters was maintained between two sampling points. The duration on the point count is one of the most obvious factors influencing the detection probability of the bird species. Keeping the above-mentioned fact in mind, each point was monitored for 20 minutes. At each point station, data was recorded on the
following variables: (a) species and number of individuals (b) stratum and height of tree (c) perch height and (d) activity. In total 110 and 125 points were sampled in Phakot and Pathri Rao watershed areas respectively from April 2005 to January 2007.

2.4 Guild Structure

Root (1967, 2001) defined guilds as group of species that exploit the same class of environmental resources (e.g., food, nest site) in a similar way. Guild studies are particularly valuable since they determine the function of avian communities and also how these communities are structured in a resource hyperspace used by a set of species. Coexistence of species in an area depends largely on various biological factors and most important being partitioning of resources (Holmes et al. 1979).

Composition of species within a guild in any area depends on the habitat related attributes like the foraging substrate, vegetation structure, vertical heterogeneity and other aspects of physiognomy (Robinson and Holmes 1982, Holmes 1986). Bird species have been observed to show preferences for perch height and food sites (Landres and MacMahon 1980). The data on such patterns was collected during the point counts, whenever a bird was encountered. Every time a bird was seen feeding on a substrate or making any attempt (e.g. canopy, tree trunk, branch or ground), foraging height and horizontal distance from the tree trunk were recorded followed by Krater et al. (2001). The data for all the individuals across all the seasons was pooled on the assumption that there is very little or no change in the foraging behavior of the birds during different time of the year. This pooling of data was done separately for PWA and PWRA. Data on 41 species of birds was recorded in PWA and 39 species in PRWA.
3. Statistical Analysis

Shannon-Weiner Index \((H')\) was taken for diversity and Margalef’s Index \((RI)\) for richness. To find out the correlation between the bird (density, diversity, richness and evenness) with the habitat parameters, Pearson’s product moment correlation coefficient was used.

Statistical analysis was done using Biodiversity Pro (Neil 1997). Each species list was treated as a separate sample. Four non-parametric statistics (Chao 1: Chao 1984, Chao 2: Chao 1987; Jacknife 1: Burnham & Overton, 1978, 1979, Heltshe & Forrester, 1983, Smith and van Belle, 1984; Jacknife 2: Burnham & Overton, 1978, 1979, Smith and van Belle, 1984, Palmer, 1991) were used to extrapolate species richness curves. Chao 1 is abundance based estimate whereas other three statistics are based on the incidence of species in samples. Rarefaction was used to compare the species diversity of two watershed areas. Rarefaction plots the expected number of species against number of individuals. It provides a measure of species diversity which is robust to sample size effect, permitting comparison between communities. Steeper curves indicate more diverse communities. So, for both the watershed areas number of species was plotted against the number of individuals for comparing the diversity of the bird communities.

The program DISTANCE 5.0 Release Beta 5 (Thomas et al. 2005) was used to compare models, assess goodness-of-fit and determine estimates of bird density for the study period, seasonally and across different habitats in both watersheds. The different models were compared using Akaike’s Information Criteria (AIC; Burnham and Anderson, 1998). By the definition the best model is the one with the least AIC value for a given season; competing models were those within 2 AIC values. When using AIC to select a particular model among alternative candidate models of the detection function, it is not unusual to
find that more than one model have similar AIC scores (perhaps differing by AIC’s of 2 or fewer). When this happens, more reliable inferences can be obtained based on the final results on an AIC weighted average of these plausible alternative models (Buckland et al. 1993; Burnham and Anderson, 2002). Variation of bird density across different habitats and seasons was tested by using Two Way Analysis of Variance. Two-way ANOVA technique allows us to estimate the effects of two independent variables on a dependent variable (Fowler et. al. 2006).

A matrix was formed of bird species and their mean perch height and horizontal distance from trunk for each species. This data set was used to generate guilds. Single linkage cluster diagram were generated using nearest neighbor method. As no objective criteria is available to use Euclidian distance for separating groups, I considered midpoint of Euclidian distance as the separating point and clusters were groups separated by Euclidian distance greater than 0.25 or the mid point value for cluster interpretation. All the statistical tests were performed following Zar (1999).

4 Results

4.1 Accuracy of Sample Size

Accuracy always increases in model communities with the increase in sample size thereby with the number of the species for all the four estimators. For PRWA Chao 1 showed the highest accuracy 81.03 % followed by Jacknife 1, Chao 2 and Jacknife 2. For PWA Jacknife 2 showed the highest accuracy 74.29% followed by Chao 2 and Jacknife 1 where as Chao 1 predicted the highest estimate thus reducing its accuracy to least 35.89%. Table4.1 shows the details of species observed using species listing during the study period along with the estimates predicted by different estimators. In case of PRWA Jacknife 2
showed the highest deviation with an accuracy value of 67.21% where as in case of PWA Chao 1 showed the highest deviation with least accuracy 35.89%.

Figure 4.1 and 4.2 illustrates the performance of four estimators for 15 –species lists for PWA and PRWA. For PWA 21 samples were used where as for PRWA 19 samples were used for the analysis. The curves show the stabilization of the number of species observed in watershed areas with respect to different estimators. 89 bird species were listed in Pathri Rao and 96 species in Phakot by species listing method.

<table>
<thead>
<tr>
<th></th>
<th>$S_{obs}$</th>
<th>Jacknife 1</th>
<th>Jacknife 2</th>
<th>Chao 1</th>
<th>Chao 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pathri Rao</strong></td>
<td>89 ± 1.76</td>
<td>117.26 ± 6.43</td>
<td>132.42 ± 7.77</td>
<td>109.84 ± 6.14</td>
<td>118.03 ± 6.12</td>
</tr>
<tr>
<td><strong>Phakot</strong></td>
<td>96 ± 0.88</td>
<td>148.96 ± 6.86</td>
<td>129.26 ± 7.86</td>
<td>267.81 ± 15.98</td>
<td>138.2 ± 5.56</td>
</tr>
</tbody>
</table>

Chapter 4 Bird Community Structure
4.2 Comparison of watershed areas in terms of bird diversity

Figure 4.3 shows the rarefaction curves for the two watershed areas. PRWA showed more steeper curve than PWA, hence PRWA was more diverse than PWA.

Figure 4.3: Rarefaction Curves for PWA and PRWA
4.3 Comparison of bird density

In PWA a total of 96 species were encountered during the study period. Overall bird density (D) was 30.48 ± 1.77/ha and density of clusters (DS) was 23.21 ± 1.20/ha. Encounter rate (n/K) was 2.92 ± 0.12 and the average cluster size (A(S)) was 1.31 ± 0.03. Bird density was highest in summer 43.13 ± 2.76/ha and lowest in winter 5.96 ± 2.61/ha. Table 4.2 gives the details of bird density, density of clusters, encounter rate and average cluster size across different seasons in PWA.

Across different habitat of PWA, density was highest in Mixed Bakli (48.85 ± 13.40 /ha) and lowest in Pine forest (18.40 ± 4.75 /ha). Two-way analysis of variance with seasons (Winter, Summer and Monsoon) and Habitat as a main effect showed that there was highly significant difference in bird density between seasons (F 2,6 = 14.87, P = 0.0005) and there was no significant difference in bird density across different habitats (F 6,12 = 1.21, P = 0.36). Table 4.3 gives the details of bird density, density of clusters, encounter rate and average cluster size across different habitats in PWA.

In PRWA a total of 89 species were encountered during the study period. Overall bird density (D) was 16.82 ± 1.60 /ha and density of clusters (DS) was 13.26 ± 0.95 /ha. Encounter rate (n/K) was 1.66 ± 0.08 and the average cluster size (A(S)) was 1.26 ± 0.07. Bird density in winter and summer was marginally different. Table 4.4 gives the details of bird density, density of clusters, encounter rate and average cluster size across different seasons in PRWA.
Table 4.2: Variation of bird density (D), density of clusters (DS), encounter rate (n/K) and average cluster size across different seasons in PWA

<table>
<thead>
<tr>
<th>Habitat</th>
<th>D ± SE</th>
<th>95% CL</th>
<th>DS ± SE</th>
<th>95% CL</th>
<th>n/K ± SE</th>
<th>95% CL</th>
<th>A(S) ± SE</th>
<th>95% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>30.48 ± 1.77</td>
<td>27.28 – 34.17</td>
<td>23.21 ± 1.20</td>
<td>20.96 – 25.69</td>
<td>2.91 ± 0.12</td>
<td>2.68 – 3.16</td>
<td>1.31 ± 0.03</td>
<td>1.24 – 1.38</td>
</tr>
<tr>
<td>Winter</td>
<td>5.96 ± 2.61</td>
<td>2.58 – 13.78</td>
<td>10.35 ± 1.13</td>
<td>8.35 – 12.83</td>
<td>1.30 ± 0.07</td>
<td>1.15 – 1.46</td>
<td>0.57 ± 0.24</td>
<td>1.0 – 1.30</td>
</tr>
<tr>
<td>Summer</td>
<td>43.13 ± 2.76</td>
<td>38.04 – 48.91</td>
<td>31.97 ± 1.93</td>
<td>28.40 – 36.0</td>
<td>4.01 ± 0.18</td>
<td>3.66 – 4.40</td>
<td>1.34 ± 0.02</td>
<td>1.29 – 1.40</td>
</tr>
<tr>
<td>Monsoon</td>
<td>29.81 ± 3.77</td>
<td>23.26 – 38.20</td>
<td>20.87 ± 2.11</td>
<td>17.10 – 25.49</td>
<td>2.62 ± 2.11</td>
<td>2.44 – 3.06</td>
<td>1.42 ± 0.10</td>
<td>1.23 – 1.65</td>
</tr>
</tbody>
</table>

Chapter 4 Bird Community Structure
<table>
<thead>
<tr>
<th>Habitat</th>
<th>D ± SE</th>
<th>95% CL</th>
<th>DS ± SE</th>
<th>95% CL</th>
<th>n/K ± SE</th>
<th>95% CL</th>
<th>A(S) ± SE</th>
<th>95% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>25.70 ±  2.89</td>
<td>20.60 - 32.06</td>
<td>19.97 ± 1.98</td>
<td>16.43 - 24.28</td>
<td>2.5 ± 0.19</td>
<td>2.15 - 2.92</td>
<td>1.28 ± 0.06</td>
<td>1.15 - 1.42</td>
</tr>
<tr>
<td>Fallow Land</td>
<td>38.57 ±  6.70</td>
<td>27.37 - 54.34</td>
<td>27.96 ± 4.50</td>
<td>20.31 - 38.50</td>
<td>3.51 ± 0.46</td>
<td>2.68 - 4.60</td>
<td>1.37 ± 0.08</td>
<td>1.21 - 1.56</td>
</tr>
<tr>
<td>Misc. Forest</td>
<td>32.82 ±  4.42</td>
<td>25.17 - 42.80</td>
<td>26.07 ± 3.31</td>
<td>20.28 - 33.52</td>
<td>3.27 ± 0.32</td>
<td>2.68 - 3.99</td>
<td>1.25 ± 0.05</td>
<td>1.15 - 1.37</td>
</tr>
<tr>
<td>Mixed Bakli</td>
<td>48.85 ± 13.40</td>
<td>28.56 - 83.53</td>
<td>30.33 ± 6.36</td>
<td>19.90 - 46.24</td>
<td>3.81 ± 0.63</td>
<td>2.68 - 5.42</td>
<td>1.61 ± 0.28</td>
<td>1.13 - 2.28</td>
</tr>
<tr>
<td>Oak</td>
<td>29.19 ±  3.66</td>
<td>22.80 - 37.36</td>
<td>23.24 ± 2.77</td>
<td>18.36 - 29.40</td>
<td>2.92 ± 0.27</td>
<td>2.42 - 3.52</td>
<td>1.25 ± 0.04</td>
<td>1.26 - 1.35</td>
</tr>
<tr>
<td>Pine</td>
<td>18.40 ±  4.75</td>
<td>11.12 - 30.44</td>
<td>15.15 ± 2.52</td>
<td>10.91 - 21.05</td>
<td>1.90 ± 0.23</td>
<td>1.48 - 2.44</td>
<td>1.21 ± 0.23</td>
<td>1.0 - 1.79</td>
</tr>
<tr>
<td>Sal</td>
<td>38.05 ±  5.41</td>
<td>28.75 - 50.37</td>
<td>28.54 ± 3.81</td>
<td>21.92 - 37.16</td>
<td>3.58 ± 0.38</td>
<td>2.88 - 4.45</td>
<td>1.33 ± 0.06</td>
<td>1.20 - 1.47</td>
</tr>
</tbody>
</table>

Chapter 4 Bird Community Structure
Table 4.4: Variation of bird density (D), density of clusters (DS) encounter rate (n/K) and average cluster size across different seasons in PRWA.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>D ± SE</th>
<th>95% CL</th>
<th>DS ± SE</th>
<th>95% CL</th>
<th>n/K ± SE</th>
<th>95% CL</th>
<th>A(S) ± SE</th>
<th>95% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>16.82 ± 1.60</td>
<td>13.96 – 20.27</td>
<td>13.26 ± 0.95</td>
<td>11.51 – 15.27</td>
<td>1.66 ± 0.08</td>
<td>1.51 – 1.83</td>
<td>1.26 ± 0.07</td>
<td>1.12 – 1.43</td>
</tr>
<tr>
<td>Winter</td>
<td>16.97 ± 1.85</td>
<td>13.70 – 21.01</td>
<td>13.18 ± 1.05</td>
<td>11.27 – 15.42</td>
<td>1.65 ± 0.08</td>
<td>1.48 – 1.84</td>
<td>1.28 ± 0.09</td>
<td>1.11 – 1.48</td>
</tr>
<tr>
<td>Summer</td>
<td>16.33 ± 3.14</td>
<td>11.20 – 23.81</td>
<td>13.61 ± 2.20</td>
<td>9.78 – 18.92</td>
<td>1.71 ± 0.19</td>
<td>1.36 – 2.14</td>
<td>1.20 ± 0.11</td>
<td>1.0 – 1.45</td>
</tr>
</tbody>
</table>
Table 4.5: Variation of bird density (D), density of clusters (DS) encounter rate (n/K) and average cluster size across different habitats in PRWA.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>D ± SE</th>
<th>95% CL</th>
<th>DS ± SE</th>
<th>95% CL</th>
<th>n/K ± SE</th>
<th>95% CL</th>
<th>A(S) ± SE</th>
<th>95% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous (L)</td>
<td>25.87 ± 4.05</td>
<td>19.02 - 35.16</td>
<td>16.72 ± 2.14</td>
<td>12.99 - 21.53</td>
<td>2.10 ± 0.19</td>
<td>1.74 - 2.52</td>
<td>1.54 ± 0.13</td>
<td>1.29 - 1.84</td>
</tr>
<tr>
<td>Deciduous (M)</td>
<td>12.60 ± 1.94</td>
<td>9.31 - 17.05</td>
<td>11.85 ± 1.29</td>
<td>9.55 - 14.69</td>
<td>1.48 ± 0.10</td>
<td>1.3 - 1.7</td>
<td>1.06 ± 0.11</td>
<td>1.0 - 1.31</td>
</tr>
<tr>
<td>Deciduous (D)</td>
<td>3.97 ± 4.53</td>
<td>0.56 - 28.16</td>
<td>12.93 ± 3.98</td>
<td>7.00 - 23.85</td>
<td>1.62 ± 0.38</td>
<td>0.98 - 2.67</td>
<td>0.30 ± 0.33</td>
<td>1.0 - 2.31</td>
</tr>
<tr>
<td>Agriculture</td>
<td>15.26 ± 4.19</td>
<td>8.91 - 26.14</td>
<td>12.11 ± 2.43</td>
<td>8.12 - 18.03</td>
<td>1.52 ± 0.16</td>
<td>1.21 - 1.90</td>
<td>1.26 ± 0.23</td>
<td>1.0 - 1.85</td>
</tr>
<tr>
<td>Riverine</td>
<td>16.97 ± 7.26</td>
<td>7.23 - 39.84</td>
<td>10.61 ± 2.88</td>
<td>6.08 - 18.51</td>
<td>1.33 ± 0.14</td>
<td>1.05 - 1.68</td>
<td>1.6 ± 0.52</td>
<td>1.0 - 3.31</td>
</tr>
<tr>
<td>Wasteland</td>
<td>2.23 ± 7.98</td>
<td>0.01 - 357</td>
<td>8.95 ± 3.14</td>
<td>4.17 - 19.19</td>
<td>1.12 ± 0.12</td>
<td>0.86 - 1.46</td>
<td>0.25 ± 0.85</td>
<td>1.0 - 41.91</td>
</tr>
<tr>
<td>Plantation</td>
<td>36.37 ± 22</td>
<td>9.16 - 144.4</td>
<td>21.22 ± 12.15</td>
<td>5.25 - 85.63</td>
<td>2.66 ± 1.20</td>
<td>0.41 - 16.96</td>
<td>1.71 ± 0.40</td>
<td>1.0 - 3.04</td>
</tr>
</tbody>
</table>

Chapter 4 Bird Community Structure
Across different habitats in PRWA, density was highest in plantation (36.37 ± 22 /ha) and lowest in deciduous (D) (3.97 ± 4.53 /ha). Two-way analysis of variance with seasons (Winter and Summer) and Habitat as a main effect showed that there was no significant difference in bird density between seasons ($F_{1,6} = 0.57, P = 0.47$) and also no significant difference in bird density across different habitats ($F_{6,6} = 1.90, P = 0.22$). Table 4.5 gives the details of bird density, density of clusters, encounter rate and average cluster size across different habitats in PRWA.

4.4 Comparison of diversity and richness

Species diversity is the number of different species in a particular area (i.e., species richness) weighted by some measure of abundance such as number of individuals or biomass where as species richness is the number of different species in a particular area (Ian et al. 2004).

In PWA overall bird diversity was 1.618 and richness was 13.869. Bird species diversity and richness was almost uniform in all the 7 habitats. Richness was highest in fallow land (9.92) followed by oak (9.779) and miscellaneous forest (9.617). Pine forest was least rich (6.445). All the habitats show high diversity values. Oak forest was highly diverse (1.533) followed by miscellaneous (1.518) and mixed bakli (1.438). Fallow land though highest in richness had a diversity value of 1.406. Pine forest was slightly low in diversity (1.328) and agriculture land was least diverse (1.315) among all the habitats.

Two-way ANOVA of variance with seasons (Winter, Summer and Monsoon) and habitat as a main effect showed that there was significant difference in bird diversity between seasons ($F_{2,6} = 6.84, P = 0.01$) and there was no significant difference in bird diversity
across different habitats ($F_{6,12} = 1.42$, $P = 0.28$). However, bird richness varied significantly across seasons ($F_{2,6} = 43.86$, $P = 3.03E-06$) but didn’t showed any significant difference across habitats ($F_{6,12} = 2.31$, $P = 0.10$). Table 4.6 gives the details of bird diversity and richness across different habitats in PWA.

In PRWA bird diversity was 1.682 and richness was 15.349. Richness was highest in deciduous forest (L) (9.811) followed by deciduous forest (M) (8.6). Wasteland had lowest richness (1.243). Diversity similarly was highest in deciduous forest (L) (1.458). However wasteland was least diverse of all habitats (0.413).

Two-way analysis of variance with seasons (Winter and Summer) and Habitat as a main effect showed that there was highly significant difference in bird diversity between seasons ($F_{1,6} = 22.25$, $P = 0.003$) and significant difference in bird diversity across different habitats ($F_{6,6} = 6.28$, $P = 0.02$). However, bird richness varied significantly across season ($F_{1,6} = 19.44$, $P = 0.004$) and across different habitat types ($F_{6,6} = 7.78$, $P = 0.01$). Table 6 gives the details of bird diversity and richness across different habitats in Pathri Rao Watershed Area.
Table 4.6: Variation of bird diversity and bird richness across different habitats in PWA and PRWA

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Richness</th>
<th>Diversity</th>
<th>Habitat</th>
<th>Richness</th>
<th>Diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>6.911</td>
<td>1.315</td>
<td>Deciduous(L)</td>
<td>9.811</td>
<td>1.458</td>
</tr>
<tr>
<td>Fallow land</td>
<td>9.92</td>
<td>1.406</td>
<td>Deciduous(M)</td>
<td>8.06</td>
<td>1.351</td>
</tr>
<tr>
<td>Miscellaneous forest</td>
<td>9.617</td>
<td>1.518</td>
<td>Deciduous(D)</td>
<td>3.53</td>
<td>0.954</td>
</tr>
<tr>
<td>Mixed bakli forest</td>
<td>8.628</td>
<td>1.438</td>
<td>Agriculture</td>
<td>4.847</td>
<td>1.147</td>
</tr>
<tr>
<td>Oak forest</td>
<td>9.779</td>
<td>1.533</td>
<td>Riverine</td>
<td>3.189</td>
<td>0.953</td>
</tr>
<tr>
<td>Pine forest</td>
<td>6.445</td>
<td>1.328</td>
<td>Wasteland</td>
<td>1.243</td>
<td>0.413</td>
</tr>
<tr>
<td>Sal forest</td>
<td>8.114</td>
<td>1.419</td>
<td>Plantation</td>
<td>1.949</td>
<td>0.743</td>
</tr>
</tbody>
</table>
4.5 Other aspects of comparison

In relation to aspects, bird richness and diversity in both the areas did not seem to follow any trend. Both richness and diversity was highest in eastern aspect but that was slightly higher than western aspect. Bird density in both watersheds on the other hand was more on eastern aspect, mainly because the sampling was carried out in morning sessions showing sampling bias.

Bird density showed a regular decline along the altitudinal gradient in PWA. Bird richness and diversity showed decline with the increase in the altitude, though decline in richness was more than in diversity. In PWRA bird density, diversity and richness increased along the altitudinal gradient from 200 to 400 meters and then showed the steep decline. Figures 4.4, 4.5 and 4.6 shows the variation of density, diversity and richness with altitudinal gradient in PWA and Figures 4.7, 4.8 and 4.9 shows variation of density, diversity and richness with altitudinal gradient in PRWA respectively.

Correlation of bird diversity with tree and shrub diversity in different habitats in PRWA showed decline in bird diversity moving from low forest cover (deciduous forest (L)) to dense forest cover (deciduous forest (D)). However, bird diversity was relatively high in riverine, agriculture and wasteland despite their low tree and shrub density. It may be due to more abundance of species which prefer open habitats like chats, larks and mynas. In PWA too, bird diversity showed more regular pattern with tree and shrub diversity.

In PWA, Pearson’s Product Moment Correlation showed negative correlation of bird density, diversity and richness with altitude. Bird diversity showed positive correlation with tree diversity ($r = 0.164 \ P < 0.01$), shrub diversity ($r = 0.144 \ P < 0.01$) and herb
diversity. Bird diversity also showed positive relation with lopping and grazing. Bird
diversity like density showed negative correlation with tree cover ($r = -0.189 \ P < 0.01$).

Bird richness showed similar trends as diversity. Richness was positively correlated with
shrub richness and negatively correlated with tree cover ($r = -0.186 \ P < 0.01$). In PRWA
bird diversity too showed strong negative correlation with altitude ($r = -0.255 \ P < 0.01$)
and slope ($r = -0.258 \ P < 0.01$) and tree cover ($r = -0.111 \ P < 0.01$). Bird diversity showed
positive correlation with tree diversity ($r = 0.206 \ P < 0.01$) and shrub cover ($r = 0.266 \ P <
0.01$).
Chapter 4 Bird Community Structure

Figure 4.4: Variation of Bird Density with Altitude in PWA

Figure 4.5: Variation of Bird Diversity with Altitude in PWA

Figure 4.6: Variation of Bird Richness with Altitude in PWA

Figure 4.7: Variation of Bird Density with altitude in PRWA

Figure 4.8: Variation of Bird Diversity with altitude in PRWA

Figure 4.9: Variation of Bird Richness with altitude in PRWA
Bird richness like diversity and density negatively correlated with altitude and slope. Richness showed strong and positive correlation with shrub cover ($r = 0.206 P < 0.01$), herb density ($r = 0.221 P < 0.01$) and herb richness ($r = 0.198 P < 0.01$).

In PRWA insectivore birds showed highest richness (10.942), diversity (1.534). This guild was followed by granivore which had richness of (4.254), diversity (1.055). Carnivore guild was least diverse. In PWA, Guild diversity was highest for insectivores (1.59) followed by granivore (1.058). Carnivore birds were found least diverse (0.579). Richness too followed the same pattern, however omnivore birds were least rich. Insectivores were almost 10 times richer than omnivores.

4.6 Guild Structure Comparison

41 species out of 96 species in PWA and 39 species out of 89 species in PRWA were used to generate guilds based on their similarities in exploiting certain sections of the vegetation for food. Figure 4.10 and figure 4.11 show the single linkage cluster diagram of birds in PWA and PRWA respectively. Four different guilds were identified in PWA and three in PRWA.

Guild 1 consists of species which forage on the ground. It includes *Lophura leucomelanos*, *Turdoides straitus*, *Passer rutilans* and *Garrulax lineatus* in PWA and doves, wagtails, mynas and larks in PRWA. Guild 2 included species like *Aethopyga siparaga*, *Dicrurus leuciphaeus*, bulbuls in PWA and *Pericrocotus ethologus* and parakeets in PRWA. These guilds occupy the top canopy and include granivore, nectarivore and insectivorous birds.
Figure 4.10: Cluster diagram of bird community based on feeding niche in PWA
Figure 4.11: Cluster diagram of bird community based on feeding niche in PRWA
But this guild was dominated by insectivorous birds in both watersheds. Guild 3 consists of bird species who exploit tree trunk for food. It includes woodpeckers and nuthatches in both watershed areas but more prominent in PWA. Guild 4 contains birds who occupy middle and lower canopy. It includes *Parus major* and *Aegithalos concinnus* in PWA and *Eumyias thalassin*, *Rhipidura albicollis* and warblers in PRWA. This guild was more prominent in PWA but could not be clearly distinguished in PRWA.

Four guilds occupied different zones in vegetation hyperspace. In general insectivore species tend to occupy top canopy and outer canopy, their mean distance from tree trunk was more than any other species. It allows them easy access to catch insects. Species like drongos and bulbuls use perch height only to position themselves to catch insects, unlike woodpeckers and nuthatches who drill the tree trunk to look for their food. Species like *Phylloscopus humei*, *Zosterops palpebrosus* and *Sylvia curruca* occupy middle canopy and thrushes exploit the lower canopy. While *Parus major* tend to be near trunk, *Aegithalos concinnus* occupies the outer side, however, these species maneuver within the canopy depending on the height of the tree. In general “Insectivore species” mean distance from trunk was more because it will give them freedom to maneuver while catching insects. Species like *Prinia socialis* prefers shrubs rather than tall trees. In general, community structure of both the sites seems to be consisting of insectivore, granivore and frugivore species, though insectivore species dominated in both the areas. The community structure of birds in PWA is more complex than the PRWA. For example 50% of area in PRWA consists of deciduous forest without structural differences and same is true for riverine and wasteland areas.
5. Discussion

In terms of bird diversity PRWA was more diverse as compared to PWA. This is mainly due to location of PRWA in tropic where as PWA lies in temperate region of the middle Himalayas. Based on the unique geographical setting of the PRWA it has the avifaunal assemblages of both Himalayas and Gangetic Plains. The overall bird listing including the occasional records accounted for 116 species for PRWA and 109 species for PWA. The estimate for PRWA, based on four estimators, is within 95% confidence limits, whereas for PWA Chao 1 overestimated the probable number of species within the watershed. The main reason behind this is that Chao 1 estimator is abundance based and bird densities were highest in PWA in summer season. The location of PWA is between the altitudinal gradient from 600–2000 meters and the area attracts most of the birds of the lower altitudes. The importance of this migration was confirmed by the sighting of *Pavo cristatus* in the PWA watershed only during summer seasons.

The structure and functioning of a biological community are affected by the characteristics, life histories and interactions of its constituent species. Which species actually co-occur in a particular place at a given time is determined by a variety of historical and ecological factors (Holmes et al. 1979). Food is an important limiting resource (Lack 1954). Density, diversity and richness were highest in summer than winter. Anderson et al. (1982) and Rosenberg et al. (1982) have earlier shown that bird density and diversity depend on the availability of insect population in different seasons. Since winters are cold in both the areas, it is possible that insect population goes down subsequently reducing population of insectivorous bird species during winter.
Bird density of agriculture fields in PWA was more than agricultural fields in PRWA. Agriculture fields are present in mosaic with surrounding woodlands in PWA. These woodlands provide breeding and feeding sites and allow colonization of individual and species (Woodhouse et al. 2005, Buckingham et al. 2006). These may also provide roosting sites for the birds. High density but lower diversity and richness of birds in agriculture fields in both areas may be due to the presence of granivore species like parakeets which forage in groups.

Oak and miscellaneous forest in PWA showed higher diversity and richness of birds. Average tree height and GHB was also highest in these habitats. Older trees provide more food availability for foliage and trunk gleaners as well as more breeding sites for birds nesting in tree holes (Thomson et al. 1999, Keller et al. 2003). Avery and Charles van Riper III (1989) attributed the high relative density of birds in Oak forests to greater complexity of habitats. Bird diversity and richness showed positive relation with tree and shrub diversity in all the habitats. Diaz (2006) found species richness increasing with shrub diversity in Oak forests. Bird species correlate with tree species was also demonstrated by Peck (1989) for British forest birds. Increase in structural complexity and floristic composition quite often are related to enrichment of associated bird communities since more heterogeneity allows more species to create niches (Poulsen 2002, Shochat et al. 2001, Laiolo 2002, Machtans and Latour 2003).

Margalef (1958) suggested sigmoid relation between diversity and cover. Grass layer adds slightly to the avian diversity. With the addition of the first shrub cover, diversity increases more rapidly. As more cover is added, diversity decreases as it restricts the mobility of the avifauna in the very dense foliage. This might explain the decrease or
negative correlation of bird density, diversity and richness with dense cover. These results were also in confirmation with Karr and Roth (1971). Henning’s and Edge (2003) and Blair (1996) put similar argument that bird species richness and diversity peaked in areas with moderate canopy cover.

Decline of bird species richness and density with elevation has been attributed to decline in forest area at higher elevations, decline in abundance and size distribution of invertebrates, competition and changes in environmental conditions (Terborgh 1971), local migration of birds along gradient (Stiles 1978), spatial variation in resources (Blake and Loiselle 2002), reduced primary productivity (Lawton et al. 1987). Some studies emphasized that low bird density and diversity at higher elevations is due to the fact that such areas act as ecological islands (Prodon et al. 2002, Kattan and Franco 2004, Diaz 2006). However apart from these reasons higher altitudes in both the study areas had dense canopy cover which affected both bird density and diversity.

Bird diversity and richness were higher on eastern aspects than western aspects in both the sites. Eastern aspects of mountains get sunlight earlier than other aspects in morning and woodland birds are known to prefer hot sunny sites than cool shaded sites (Mitchell et al. 2006). Since sampling was carried out in morning hours only, therefore high bird density and diversity may be due to warmth in the eastern aspect in the morning. The results from the Pathri Rao watershed area were in contrast probably because half of the area had flat terrain with no marked aspects.

Bird density and richness in both the areas showed tolerance towards grazing and lopped areas. Laiolo et al. (2003) put forward the view that grazing is known to have little effect
on typical open habitat bird species. This study confirms the above pattern. Daniels (1989) and Javed (1997) found an increase in bird species diversity when forests are disturbed. Secondary vegetation growth as a result of lopping or grazing provide more scope for forest generalist species to exploit for food and resting (Beehler et al. 1987, Terborgh and Weska 1969). Bock and Webb (1984) argued that birds generally respond to change in vegetation structure as a consequence of grazing rather than to the presence of cattle per se but avian response vary from site to site (Wein and Dyer 1975). Urbanization is accompanied by changes in bird species richness but such changes whether positive or negative depend upon on the degree of urbanization.

Both watershed areas were disturbed due to human activities. However, disturbance in PWA is more restricted to lopping and grass cutting whereas, in PRWA more commercial activities were carried out as a result of establishment of industrial setups. Rural activities modify wildlife habitat and increase vegetation structure and variety (Crooks et al. 2004, Glennun and Porter 2005, Chapman and Reich 2007). Native habitats mixed with cropland create a landscape with habitat for a wide variety of species (Soderstom and Part 2000, Burke and Nol 2000).