EVALUATING THE IMPORTANT BIRD AREAS NETWORK IN INDIA FROM A BIOGEOGRAPHIC AND CONSERVATION PERSPECTIVE

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ABSTRACT

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The Important Bird Areas network comprises several hundred localities that contain high levels of bird diversity. Many of the Important Bird Areas (IBAs) exist within larger regions known as Endemic Bird Areas (EBAs). Given the rapid industrialization and population growth of India, it is imperative to preserve the natural areas and unique biodiversity of the nation. We undertook a study to evaluate whether IBAs in each of seven EBAs adequately represented the regional endemic bird faunas. We examined statistical associations between endemic bird diversity and factors such as

IBA land area, habitat variety, local climate, land use practices, and geographic location. Well-known principles and patterns from biogeography suggest that these factors should influence endemic bird diversity. Linear regression and probit regression models were used for data analysis. Although area and habitat variety positively influenced IBA endemic bird diversity, no single factor had a consistent and dominant effect in every EBA. Rather, several factors were jointly associated with diversity, and they varied for each EBA. Because no single factor is strongly associated with diversity, we recommend that a holistic approach be taken during the planning process wherein new IBAs are located or designated based on multiple factors.

KEYWORDS

biodiversity, conservation biogeography, endemic avifauna, endemic bird areas, important bird areas, Indian avifauna

CHAPTER ONE

INTRODUCTION[*]

Conservation biogeography is an emerging discipline wherein principles from biogeography are applied to address problems and create solutions for conserving biodiversity on a large scale (Whittaker et al., 2005). For example, the effectiveness of reserve networks in preserving wildlife species and biodiversity in general can be evaluated by examining the extent to which the reserves capture biogeographic and ecological patterns. One such pattern, widely studied and documented, is the species-area relationship (Williams, 1943; Preston, 1962; Brown, 1971; Simberloff, 1976; Connor and McCoy, 1979; Hanski and Gyllenberg, 1997; Lomolino, 2000; Losos and Schluter, 2000; Whittaker et al. 2005). This relationship describes the increase in the number of species as the area of reserves increase; larger reserves contain more species than do smaller reserves. Various explanations have been proposed for this pattern (Rosenzweig, 1995; Losos and Schluter, 2000; Whittaker et al., 2001; Drakare et al., 2006; Kallimanis et al., 2008); most notably, increasing area typically entails an increase in habitat variety (Ricklefs and Lovette, 1999; Storch et al., 2003) that leads to a greater

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number of species given that species are often adapted to one or a few particular habitats. Therefore, in any network of reserves, we would expect a greater number of species to occur in the larger reserves than in the smaller ones; any serious departure from this pattern might indicate that the reserves are not functioning as planned. The latitudinal diversity gradient is another well-documented pattern in biogeography; it describes an increase in species diversity from temperate latitudes to tropical latitudes (Pianka, 1966; Gaston, 2000; Arita and Vazquez-Dominguez, 2008). This pattern suggests that geographically extensive networks should strive to create and/or plan new reserves with a bias toward locating them at lower latitudes.

Reserve network planning is important everywhere, but particularly in India. The country is among the top ten nations in total biodiversity (Islam and Rahmani, 2005) and India continues in the middle stages of demographic transition (Lee, 2003; Veron, 2008). The biodiversity of India faces increasing pressure from growth of human population and associated land development and natural resource extraction. These processes lead to loss and/or alteration of natural habitat. In particular, the unique bird fauna of India may be most threatened. The Indian subcontinent has 1,225 of the world's 9,000 bird species and represents 48 of the 75 bird families (Grimmett, et al., 1998). India has 74 endemic or restricted-range bird species (38 entirely within India), ranking it 14th among all 150 countries having at least one restricted-range species (Stattersfield et al., 1998). Restricted-range bird species have breeding ranges covering less than 50,000 km^2 (Stattersfield et al., 1998). Of the 74 species, 27 are globally threatened as defined by Birdlife International and other conservation organizations.

As a major step toward conserving global bird diversity, Birdlife International identified 218 geographical regions as Endemic Bird Areas (EBAs) around the world. By definition, an EBA encompasses the breeding ranges of two or more restricted-range bird species. Birdlife International has also recognized specific protected areas (e.g., nature preserves, wildlife refuges, and national parks) and designated these as Important Bird Areas (IBAs) given their substantial or unique bird diversity. Within India, there are 466 IBAs and 201 of these are within seven EBAs (Table 1, Fig. 1) (Stattersfield et al., 1998). The various protected areas designated as IBAs were not originally created for the sole purpose of preserving bird diversity. Nonetheless, we can evaluate the effectiveness of the Indian IBA network in accomplishing this purpose, particularly with regard to obtaining knowledge that might inform the creation of new IBAs if and when that becomes possible.

Most previous research on Indian avifauna has focused on specific regions of the country or particular species (Ripley and Beehler, 1989; Adler, 1994; Rahmani and Soni, 1997; Sankaran, 1997; Sankaran, 1998; Zacharias and Gaston, 1999; Vijayan, et al., 2000; Bhagwat, et al., 2005; Scharlemann, et al., 2005; Jathar and Rahmani, 2006; Pande et al., 2007). To date, no study has been published on the conservation biogeography of endemic avifauna in India. As a consequence, no research has collectively examined the characteristics of all the IBAs and tested for associations between bird diversity and land area, habitat variety, local climate, land use practices, and geographic locations of the IBAs. The present study addressed the following questions within each EBA: (1) Does endemic bird diversity within an IBA increase with increasing area? (2) Is diversity within IBAs affected by the number and variety of habitats and hence, potential ecological niches within IBAs? (3) Is diversity potentially affected by anthropogenic factors related to land use? (4) Is diversity affected by geographic location of an IBA? (5) To what extent are IBAs within an EBA redundant or complementary with respect to the endemic bird species that they contain? Answers to these questions will assist policy-makers, government officials, and conservationists in planning for the future protection of endemic birds and their habitats in India.

MATERIALS AND METHODS

Data – EBAs and IBAs of India

The data for this study were compiled from Islam and Rahmani (2005). Of the 201 IBAs that occur within the seven EBAs in India, 45 were deemed "data-deficient" by Islam and Rahmani (2005) and were excluded, leaving 156 IBAs in the analyses. Among the seven EBAs, there are 69 endemic bird species representing 29 families (Appendix 1). Twenty of the species are in the family Timaliidae (Old World babblers) and seven are in Phasianidae (quails, partridges, pheasants). None of the remaining families are represented by more than four species; therefore, overall the 69 endemic species include substantial taxonomic diversity. Of most importance, 26 of the species are on the International Union for Conservation of Nature (IUCN) "Red List", being categorized as "critically endangered", "endangered", or "vulnerable". An additional 20 species are categorized as "near threatened" (Birdlife International 2003) (Appendix 1). Most of the EBAs contain between 9 and 21 endemic species (Table 1).

The EBAs vary substantially in area and in number of IBAs (Table 1); in general the IBAs of an EBA are dispersed throughout the EBA (Fig. 1). Area of IBAs varies from being very small (< 1 km^2) to very large (> 4,500 km^2), although the mean IBA area is typically several hundred km^2 (Table 1). Ownership of IBAs includes large national parks and tiger preserves administered by the government of India as well as small privately-owned nature preserves (Islam and Rahmani 2005).

We used several IBA-level variables that directly and indirectly quantify the number of potential ecological niches within an IBA. Habitat heterogeneity was quantified by the total number of habitat types found in an IBA. We categorized habitat types following Islam and Rahmani (2005), using the Champion and Seth (1968) classification of forest types and climatic zones in India. For the tropical zone, seven habitat types were defined: (1) wet evergreen forest, (2) semi-evergreen forest, (3) moist deciduous forest, (4) littoral and swamp forest, (5) dry deciduous forest, (6) thorn forest, and (7) dry evergreen forest. For the sub-tropical zone, three habitat types were defined: (8) broadleaf hill, (9) pine forest, and (10) dry evergreen. In the temperate zone, habitat types were (11) montane wet forest, (12) Himalayan moist forest, and (13) Himalayan dry forest. Habitat types in the alpine zone were (14) sub-alpine forest, (15) moist scrub, and (16) dry scrub. We included two additional categories for (17) lakes and (18) grasslands. The vast majority of IBAs (146/156) had 2 – 4 of these broad habitat types; no IBA had more than five (Table 1). For each IBA we also determined altitudinal range (the difference between the highest and lowest elevations within the IBA), historical average annual rainfall, and seasonal temperature range (the difference between the highest and lowest annual temperature). Again, there is some variation in these variables among EBAs and variation among IBAs within most EBAs (Table 1). Altitudinal range is an indirect measure of habitat variety given that vegetation and plant associations change substantially along altitudinal gradients. Annual rainfall and seasonal temperature range may also indirectly measure habitat and niche variety in that both of these climatic factors can affect net primary productivity and the amount of energy entering into an ecosystem assuming greater productivity leads to more resources (Wright, 1983; Currie, 1991; Hawkins et al., 2003; but also see Rohde, 1992; Rahbek et al., 2007). In addition, these two climate variables are annual means and hence more likely to be measured accurately for each IBA compared to variables representing climatic extremes.

For each IBA, we obtained a list of land uses (e.g. agriculture, energy production, tourism) and anthropogenic threats (e.g., habitat destruction, pollution) as reported by Islam and Rahmani (2005). We also recorded latitude and longitude of each IBA for use in subsequent analyses.

Species-area relationship

To test whether the diversity of endemic birds within IBAs increases with increasing area, the species-area relationship (among the IBAs) within each EBA was assessed using linear regression of the log10 values of both number of species and area, as is standard practice. This analysis was applied only to the Western Ghats, Andaman Islands, Western Himalayas, and Eastern Himalayas EBAs. The other three EBAs did not have a sufficient number of species or IBAs for a meaningful analysis.

Niche and habitat variety

To assess niche and habitat variety we expressed the number of endemic bird species within an IBA as a ratio of the total number of endemic species in the EBA, hereafter referred to as the species richness ratio. The ratio allows for a more meaningful comparison among EBAs given that these differed in total number of endemic species (Table 1). Because the ratio is a proportion, its relationship with explanatory variables is expected to be sigmoidal rather than linear. Thus, a probit model with a log-normal transformation of the response variable (Bliss, 1935; McCullagh and Nelder, 1989) was used for all regression analyses. Maximum likelihood was used to estimate parameters of the regression models. For each EBA, we tested the effect of habitat and niche variety on endemic bird diversity of IBAs by fitting probit regression models with habitat heterogeneity, altitudinal range, average annual rainfall and seasonal temperature range as predictors. Each variable, along with IBA area was first fit individually in a probit model. Multiple probit regression models were then constructed but only for the Western Ghats and Eastern Himalayas EBAs, due to sample size constraints. In all models, IBA area was included as an independent variable, in order to adjust for its association with species richness ratio.

Anthropogenic factors

The association of species richness ratio of endemic birds with anthropogenic factors was examined by summarizing the threats and land uses in each IBA, and observing the patterns of anthropogenic activity in them. Each threat was coded as a binary variable (present = 1, absent = 0) and entered individually as the predictor, along with IBA area, into a probit regression model.

Geographic locations of IBAs

Within each EBA, the association between species richness ratio per IBA and geographic location was examined using separate probit models with each IBA's latitude and longitude as predictors of species richness ratio, adjusting for IBA area.

Similarity of species composition within IBAs

To assess similarity in species composition of IBAs within EBAs, a pair-wise Sorensen's similarity coefficient (Sorensen, 1948; Pielou, 1977; Krebs, 1998) was calculated for all pairs of IBAs within each EBA. The index is widely used to quantify the similarity in species composition among samples and is similar to other pairwise similarity metrics, e.g., Jaccard index (Krebs, 1998). The index is $S = 2a/(2a + b + c)$ where a = number of shared species in IBA1 and IBA2 (joint occurrences), b = number of species in IBA2 but not in IBA1, c = number of species in IBA1 but not in IBA2, and d = number of species absent in both IBA1 and IBA2 (zero-zero matches). The index = 1 when two samples (e.g., IBAs) are identical in species composition and zero when two samples do not share any species. The mean similarity coefficient and standard deviations for each EBA, averaging across all pairs of IBAs was calculated.

All analyses except the similarity assessment were conducted on SPSS 17.0 software. Splus 8.0 software was used to calculate Sorensen's similarity index.

RESULTS

Species richness ratio

Species richness ratios varied from 0.21 (Western Ghats) to 0.81 (Nicobar Islands) across EBAs. The Eastern and Western Himalayas EBAs had low mean species richness ratios and low variation in richness in IBAs as well (Table 2), indicating that most IBAs in these EBAs had lower levels of species richness. The Western Ghats EBA had comparatively greater variation (Table 2), indicating that some IBAs in this EBA had higher richness while others did not. The Andaman Islands had the highest mean species richness ratio and moderately high variance, indicating good species representation in some IBAs but not others.

Species-area relationship

A statistically significant positive linear species-area relationship was observed among IBAs in the Andaman Islands EBA ($t = 3.35$, $ß = 0.26$, $p = 0.01$) and Eastern Himalayas EBA ($t = 2.29$, $ß = 0.13$, $p = 0.026$), indicating that larger IBAs had a greater number of endemic species than smaller IBAs. A marginally significant positive linear species-area relationship was observed in the Western Himalayas EBA ($t = 1.91$, $ß = 0.19$, $p = 0.076$). No statistically significant species-area relationship was observed in the IBAs in the Western Ghats EBA ($t = 0.58$, $ß = 0.02$, $p = 0.566$) including when a statistical outlier IBA having only one endemic species was removed.

Niche and habitat variety

Probit analysis revealed a significant ($p < 0.0001$) positive association between habitat heterogeneity and species richness ratio among the IBAs of the Western Ghats EBA only (Table 2). However, altitudinal range was significantly and positively associated with IBA species richness ratio in the Western Ghats ($p < 0.0001$), Andaman Islands ($p = 0.001$) and the Eastern Himalayas EBAs ($p < 0.0001$) (Table 2). Average annual rainfall was significantly ($p < 0.05$) and positively associated with IBA species richness ratio in the Western Ghats EBA, but was negatively associated with IBA richness in the Eastern Himalayas (Table 2). Temperature range was not associated with IBA species richness ratio in any of the EBAs. Western Himalayas was the only EBA where none of the variables was significantly associated with IBA species richness ratio (Table 2).

Multiple probit regression analysis in the Western Ghats EBA indicated that habitat heterogeneity and altitude range were significantly associated with species richness ratio, while adjusting for the effect of IBA area. Controlling for habitat heterogeneity, larger altitude ranges were associated with a higher species richness ratio ($Z = 4.73$, $ß = 0.001$, $p < 0.0001$). Reciprocally, controlling for altitude range, higher habitat heterogeneity was associated with a higher species richness ratio ($Z = 2.94$, $ß = 0.159$, $p = 0.003$). In the Eastern Himalayas EBA, habitat heterogeneity and annual rainfall were found to be significantly associated with the species richness ratio. Controlling for habitat heterogeneity, higher annual rainfall was associated with a lower species richness ratio ($Z = -2.79$, $ß = -0.0001$, $p = 0.005$). Controlling for annual rainfall, higher habitat heterogeneity was associated with a higher species richness ratio ($Z = 2.5$, $ß = 0.135$, $p = 0.013$).

Geographic locations of IBAs

In the Western Ghats EBA, a significant change in species richness ratio was observed along both latitudinal ($p < 0.0001$) and longitudinal ($p < 0.0001$) gradients after adjusting for IBA area (Table 2). On average, species richness ratio decreased significantly moving north away from the equator, and increased significantly moving east or inland. In the Andaman Islands EBA, there was a longitudinal effect ($p < 0.01$, Table 2), but no latitudinal effect. In the Eastern Himalayas EBA, a significant latitudinal effect was observed ($p < 0.05$), indicating higher species richness ratios moving north within this EBA. A significant longitudinal effect in this EBA ($p < 0.05$), indicated higher species richness ratio going east (Table 2). No significant latitudinal or longitudinal effects were seen in the Western Himalayas EBA.

Anthropogenic factors

Most IBAs in each EBA had multiple varied types of land uses (Fig. 2). Across all the EBAs, tourism and recreation, nature conservation and research, and forest resource utilization were the most common land uses. Habitat destruction and poaching were the most common anthropogenic threats to bird diversity within the IBAs; within most EBAs, 50% or more of the IBAs faced these threats (Fig. 3). Overgrazing by livestock and the collection of fuel wood were common threats in all EBAs except for the island EBAs (Andaman Islands and Nicobar Islands). Development of land for commercial and industrial use were particular threats within the Andaman Islands and Nicobar Islands EBAs. Pollution and pesticide use was not a major threat except in the Southern Tibet EBA. Agriculture was not a major threat in any of the EBAs (Fig. 3).

A more thorough evaluation of the threats to the IBAs was provided by the probit analyses testing for a difference in the species richness ratios of IBAs facing a particular threat and those not facing the threat. After a Bonferroni adjustment of the significance level within each EBA, we found only five instances of a significant difference out of 27 total comparisons. In the Western Ghats EBA, IBAs having the threat of habitat destruction had a lower mean ratio (0.50, sd = 0.23, n = 43) than those without this threat

(0.71, sd = 0.24, n = 13). In this EBA, IBAs with tourism/traffic as a threat had a lower ratio (0.44, sd = 0.26, n = 16) than did IBAs without this threat (0.59, sd = 0.22, n = 40). In the Andaman Islands EBA, IBAs with the threat of industrial/commercial development actually had a higher ratio (0.82, sd = 0.06, n = 8) than those without the threat (0.61, sd = 0.30, n = 7). Lastly, in the Eastern Himalayas EBA, IBAs with overgrazing had a lower ratio (0.14, sd = 0.12, n = 16) than those without this threat (0.26, sd = 0.16, n = 35); a nearly identical result was obtained with fuel wood and non-timber forest produce collection as a threat given that the same IBAs tended to have both of these threats.

Similarity of IBAs within an EBA

In the Western Ghats EBA, IBAs were moderately similar (mean $S = 0.54$, sd = 0.24, n = 1653) in species composition, with half of all pairs of IBAs having $S > 0.57$. IBAs within the Andaman Islands EBA had the greatest similarity (mean $S = 0.77$, sd = 0.32, n = 105), with half of all pairs of IBAs having $S > 0.9$. Similarity among IBAs in the Western Himalayas and Eastern Himalayas EBAs was relatively low (mean $S = 0.31$ and 0.22, sd = 0.32 and 0.24, n = 120 and 1275, respectively), with half of all pairs of IBAs having $S < 0.29$ in the Western Himalayas, and $S < 0.18$ in the Eastern Himalayas EBA. Because the Assam Plains EBA had just 3 species, and there were only 3 IBAs each in the Nicobar Islands and Southern Tibet EBAs, similarity indices were not calculated.

DISCUSSION

Our evaluation of the Important Bird Areas network of India uncovered general patterns that can assist policy-makers, government officials, and conservationists in planning for the future protection of endemic birds and their habitats. We examined associations between endemic bird diversity and the biogeographic factors that in theory should affect local diversity within individual IBAs, and thus also inform the planning of future reserves. For example, the species-area relationship may have practical use in conservation such as enabling prediction of species loss due to future loss of habitat or area and possible species gain by increasing the size of reserves (Doak and Mills, 1994; Brooks et al., 1997; Ney-Nifle and Mangel, 2000; Smith, 2010). In the present study, we used the species-area relationship to determine if the area of an IBA had the expected positive effect on endemic bird diversity.

Of the four EBAs analyzed, three (Eastern Himalayas, Andaman Islands, and Western Himalayas) showed a positive species-area relationship and one (Western Ghats) did not show a significant relationship. In the Eastern Himalayas, this is a particularly critical observation, since some of the project sites of hydroelectric dams being constructed on the Teesta River are located within the boundaries of IBAs within this EBA (Islam and Rahmani, 2005). Development projects undertaken within this EBA should be planned with caution, since a reduction in viable IBA area is correlated with a reduction in species richness of endemic birds. This caution is also warranted for the IBAs in the Andaman Islands and Western Himalayas EBAs; that is, any future increase in habitat destruction or loss of reserve area could potentially lead to a loss of endemic bird species. In spite of having IBAs of variable size, a species-area relationship was not detected in the Western Ghats EBA. In this EBA, endemic species richness is not well correlated with IBA area, as many of the larger IBAs have relatively low species richness and smaller ones have relatively high richness. Thus, any new IBAs would not necessarily need to be large in order to be useful for preserving endemic bird species. Therefore, in this EBA, designation of new IBAs should not be based on size alone. On the other hand, the positive species-area relationship for the Andaman Islands, Western Himalayas, and Eastern Himalayas EBAs suggests that larger IBAs are more likely to preserve more endemic species than are smaller IBAs.

In addition to area, the geographic isolation of an IBA (distance between it and another IBA or source of endemic birds) could potentially affect the number of endemic species within the IBA. In the context of island biogeography theory (MacArthur and Wilson 1967), area and isolation affect the number of species on “islands” (true islands as well as habitat fragments). “Islands” further from the source have fewer species. Although isolation of IBAs was not examined in the present study, within each EBA none of the IBAs appears to be substantially distant from others (Fig. 1).

We tested for an association between endemic bird diversity and the habitat heterogeneity of IBAs. As with most organisms, habitat matters to birds. That is, species have distinct habitat preferences and requirements such that a greater habitat heterogeneity (or number of distinct types) results in greater species diversity. Habitat restrictions may be particularly important for endemic species and in part a reason for their endemism. Thus preservation of multiple endemic bird species might require reserves with substantial habitat heterogeneity. Our study revealed a significant positive association between habitat heterogeneity and species richness ratio for the IBAs in the Western Ghats EBA. Therefore, it would be preferable for new IBAs in the Western Ghats to contain a wide variety of habitat types. Because no association was found in the Western Himalayas or the Eastern Himalayas EBAs, habitat heterogeneity here does not correlate well with species richness ratio. In these two EBAs, new IBAs with multiple habitat types (2, 3, 4, or 5) would be equally effective in preserving endemic bird species.

In this study we also considered mean annual rainfall and seasonal temperature range of an IBA to be indirect indicators of habitat variety and niche availability. Both variables positively affect the amount of vegetation and hence the amount of biomass or energy base of a food chain (Currie, 1991; Hawkins et al., 2003). Greater amounts of energy at the base (lower trophic levels of a food chain) then allow for a greater number of niches at the higher levels occupied by birds. There was a significant positive association between average rainfall and species richness ratio in the Western Ghats EBA. In contrast, a negative association between average rainfall and species richness ratio was found in the Eastern Himalayas EBA. No significant association was found in the Western Himalayas. Temperature range was not associated with IBA species richness ratio in any of the EBAs, even though the IBAs (within an EBA) varied substantially in this variable. These mixed results indicate that endemic bird diversity does not necessarily increase with niche availability even assuming that rainfall and temperature indirectly produce more niches (food resources) through an effect on vegetation. Therefore, new IBAs need not be located with regard to local climatic variations; other factors likely supercede climate as a factor in determining local diversity of endemic birds.

Altitudinal range can also be regarded as a composite measure for the number of habitat types, as well as climatic gradients (precipitation and temperature) that might affect vegetation and hence habitat *at a relatively fine scale*. Thus, IBAs with large altitudinal ranges were expected to have more endemic bird species. Significant positive relationships of IBA species richness ratio increasing with increasing altitudinal range of the IBA were observed in the Western Ghats and Eastern Himalayas EBAs. Therefore, new IBAs in these EBAs will be more effective in preserving endemic bird species if they span a wide altitudinal range. No such relationship was observed in the Andaman Islands or the Western Himalayas EBAs, so that conservationists need not consider altitudinal range as a factor in locating or designating new IBAs.

Only the Western Ghats and Eastern Himalayas allowed testing with multiple probit regression to isolate individual effects of habitat heterogeneity, altitude range, average rainfall, and temperature range (while adjusting for IBA area) on endemic bird diversity. In the Western Ghats EBA, habitat heterogeneity and altitude range had significant positive associations with species richness ratio. Therefore in this EBA, new IBAs should preferably have substantial altitudinal range along with multiple habitat types. In the Eastern Himalayas EBA, habitat heterogeneity and annual rainfall were significant factors. As with the univariate analysis, rainfall had a negative association with species richness ratio. After accounting for this negative association (by including rainfall in the model), greater habitat heterogeneity was associated with greater diversity of endemic birds. Overall, habitat heterogeneity appears to be a key variable since it provides a mix of different niches that possibly accommodate various species.

The latitudinal diversity gradient is another well-known and widely studied biogeographic pattern (Pianka, 1966; Rohde, 1992; Rosenzweig, 1992, 1995; Gaston, 2000; Hawkins, 2001; Willig et al., 2003; Arita and Vazquez-Dominguez, 2008). It describes an increase in species richness from temperate (high) latitudes to tropical (low) latitudes and is typically found for gradients of hundreds to thousands of kilometers. The causes of the pattern are vigorously debated; most explanations invoke either long-term evolutionary processes or shorter duration ecological processes (Gaston, 2000). Regardless, the pattern is important to conservation planning because it suggests that the latitudinal (and perhaps longitudinal) location of a current or planned preserve might influence its species richness. Ideally, large-scale networks of protected areas (e.g., IBAs within EBAs) will capture any latitudinal (or longitudinal) richness gradient that may exist.

More specifically, our analysis of geographic location addressed whether new IBAs should be intentionally located within an EBA on the basis of geographic location alone. A significant negative association was found between latitude and species richness ratio in the Western Ghats. Since this EBA has its greatest extension in the north-south direction, this indicates that IBAs in the southern states of the EBA have greater species richness than those in the northern states. A more detailed analysis of the qualitative differences between the IBAs in the northern region and southern region of this EBA could provide guidance on how the northern IBAs could better protect endemic birds. In addition, since the southern IBAs have greater species richness ratios, new IBAs could be more useful in the northern region for better representation of regional fauna. There was also a significant positive association of longitude with species richness ratio in the Western Ghats EBA. In the Western Ghats this indicates increasing species richness moving away from the coast.

In the Eastern Himalayas EBA, a significant positive association was found with latitude. This EBA extends over most of northeast India, and so this finding indicates that the northern states such as Sikkim and Arunachal Pradesh have greater species richness ratio compared to the southern states in the region such as Mizoram and Manipur. By itself, this result suggests that new IBAs should be located in the northern states given that higher latitude preserves are more likely to contain more of the endemic species of the EBA. However, IBAs in all four states face serious threats. The greatest threats in Mizoram and Manipur are poaching, jhum or shifting cultivation, and lack of public awareness (Islam and Rahmani, 2005). In Sikkim and Arunachal Pradesh, major hydroelectric dam projects threaten to disturb the relatively pristine habitat that exists in these states. It would be certainly preferable to bring in more areas under protection in the form of reserves in these northern states. The IBAs within the Eastern Himalayas EBA also exhibited a significant association of species richness ratio with latitude. In the Eastern Himalayas, protection of the pristine forests of the easternmost states could be prioritized so as to preserve the higher levels of species richness within the region.

The analysis of the anthropogenic factors associated with each IBA was intended to determine whether high richness IBAs face different threats than do low richness IBAs. The most common threats across all EBAs were habitat destruction, poaching, grazing, firewood/NTFP collection, and industry/development. However, statistical analyses of these threats failed to reveal any strong patterns with regard to the consistency and importance (i.e., IBAs with the threat having lower diversity than IBAs without) of any one threat across all EBAs or any one EBA having all threats being significant. Nonetheless, endemic bird diversity (and that of other wildlife) in India is likely threatened by factors such as habitat destruction and overexploitation. More specifically, human activities such as livestock grazing and firewood extraction have steadily increased over the past two decades, leading to erosion of habitat quality

(Sharma, et al., 2000; Chettri, et al., 2002). At a broader level, the current development strategy in India favors rapid growth and widespread industrialization, with particular emphasis on greater natural resource extraction and an increase in water-and-chemical intensive agriculture. The development is fueled by foreign investment that also indirectly leads to a more affluent populace with greater buying power and a need for more space and resources (Vyas et al, 1998). The resource extraction necessary to meet these needs leads to a steady erosion of the quality and extent of forest area in the country (Barve et al., 2005). In order to facilitate the economic development, the environmental impact assessment process in India is undergoing changes resulting in compromises to the quality of protection for the environment (Saldanha et al., 2007) further exacerbating the effects of habitat destruction.

With under-regulated economic development and weak environmental protection (Saldanha et al, 2007) the endemic bird diversity of individual IBAs could be adversely affected by habitat destruction, pollution, and other threats. However, one desired outcome of a network of reserves is that *collectively* the reserves protect diversity so that harm to any one reserve does not adversely affect regional diversity. In such a scenario it is desirable to have reserves that are both similar in species composition and highly representative of the regional fauna. Similarity in species composition also needs to be assessed in the planning process as it can inform us as to whether new reserves are needed due to low similarity among current reserves. Our similarity analysis evaluated the need for new IBAs; we examined how well the current ones (as a group within each EBA) represent the endemic bird fauna. Of all the EBAs analyzed, IBAs within the Andaman Islands were the most similar in species composition (mean $S > 0.7$). The IBAs all have very similar habitat composition, altitudinal ranges, temperature and rainfall patterns. It is therefore not surprising that they should also have similar species compositions. The mean species richness ratio in these islands is also quite high, indicating that the endemic birds of this EBA are being well protected. New reserves are probably not necessary from the perspective of representing the regional fauna. In contrast, IBAs in the Eastern and Western Himalayas EBAs are relatively dissimilar (mean S = 0.22 and 0.31 respectively). Their average species richness ratios are also lower than the other EBAs. This could be due to insufficient monitoring studies (and incomplete species lists) in some of the remote IBAs in these regions. However, it is still advisable to undertake studies to identify which species of birds in these EBAs are the rarest, and improve current IBAs or create new ones to provide the conditions that would sustain them. In the Western Ghats EBA, the IBAs are moderately similar (mean S = 0.54) such that new reserves could be created or designated so as to collectively increase representation of the regional endemic bird diversity and to lessen the consequences of harm to any one IBA.

CONCLUSION

Our study of the conservation biogeography of endemic bird areas in India enabled an assessment of factors that could affect endemic avian species richness at a regional level. Our findings indicate that various biogeographic and anthropogenic factors often act together in determining how well an individual IBA represents the regional endemic bird fauna. Consequently, a holistic approach taking multiple factors into consideration is advisable in order to create and maintain effective reserves. The factors that are most influential vary across EBAs, so that reserve network planning might proceed in a slightly different way in each EBA. Long, et al. (1996) have noted that EBAs can be used to identify centers of overall endemism; and Thirgood and Heath (1994) suggest that centers of endemism for birds will also be centers of endemism for other taxa. Thus it is critical to preserve and protect IBAs not only for the protection of endemic bird species, but for the protection of biodiversity in general. India is currently undergoing rapid economic growth, increasing the consuming power of more people each year. At this juncture it is vital to ensure that the quality of the country's biodiversity is not compromised to facilitate development. The findings of this study could assist in formulating conservation planning for reserve networks in India, so that the country's unique and abundant biodiversity, particularly its endemic avifauna, is effectively protected.

Table 1. Characteristics of the Endemic Bird Areas (EBA) and Important Bird Areas (IBA) within India.

EBA	Area (km^2)	Number of species	Number of IBAs	Area (km^2) [a]	Habitat heterogeneity [a]	Altitudinal range [a]	Annual rainfall [a]	Temperature range [a]
Western Ghats	61,000	16	58	255 (0.12, 987)	2.9 (1, 5)	1157 (296, 2514)	271 (17, 650)	19 (7, 32)
Andaman Islands	8,200	13	15	231 (3.5, 977)	2.9 (2, 3)	214 (27, 739)	377 (330, 380)	12 (12, 14)
Nicobar Islands	1,800	9	3	435 (17, 853)	3.7 (3, 4)	323	380 (380, 380)	12 (12, 12)
Western Himalayas	130,000	11	16	551 (26, 2100)	3.1 (2, 4)	3313 (698, 6300)	158 (83, 309)	31 (22, 42)
Eastern Himalayas	220,000	21	51	613 (1, 4576)	3.0 (1, 5)	2000 (80, 7298)	275 (150, 1250)	28 (20, 45)
Assam Plains	126,000	3	18	372.6 (39, 1200)	3.2 (2, 4)	855 (10, 3017)	272 (382, 675)	27 (20, 33)
Southern Tibet	63,000	1	3	225 (50, 500)	2.3 (2, 3)	2800 (2500, 3199)	–	53 (45, 60)

[a] Values represent the mean over all IBAs with minimum and maximum values in parentheses. Units are as follows: habitat heterogeneity – number of habitat types, altitudinal range – m, annual rainfall – cm, and temperature range – degrees Celsius. See text for detailed descriptions of the variables.

Table 2. Results of the probit analyses (z-value and p-value) testing for an association between species richness ratio and each variable among the Important Bird Areas of each Endemic Bird Area (EBA)[a]. Significant results are bolded. EBA sample sizes as in Table 1.

EBA	Species richness ratio [b]	Habitat heterogeneity	Altitudinal range	Annual rainfall	Temperature range	Latitude	Longitude
Western Ghats	0.55 (0.24)	**3.65, 0.0001**	**5.09, 0.0001**	**2.42, 0.015**	1.07, 0.286	**-6.57, 0.0001**	**5.44, 0.0001**
Andaman Islands [c]	0.72 (0.22)	–	**3.24, 0.001**	–	–	0.55, 0.58	**-3.12, 0.002**
Western Himalayas	0.21 (0.13)	1.04, 0.30	0.24, 0.81	0.54, 0.59	-0.49, 0.624	1.28, 0.20	-1.02, 0.31
Eastern Himalayas	0.22 (0.16)	1.62, 0.11	**4.20, 0.0001**	**-2.77, 0.006**	-0.28, 0.782	**2.33, 0.02**	**2.17, 0.03**

[a] The following EBAs could not be analyzed due to insufficient numbers of species or IBAs: Nicobar Islands, Assam Plains, and Southern Tibet.
[b] Values are means over all IBAs with standard deviation in parentheses. Means and standard deviations for Nicobar Islands, Assam Plains, and Southern Tibet were 0.81 (0.13), 0.44 (0.16), and 0.67 (0.58) respectively.
[c] Probit analysis was not conducted for habitat heterogeneity, annual rainfall, and temperature range of the IBAs of the Andaman Islands due to lack of variation in these variables.

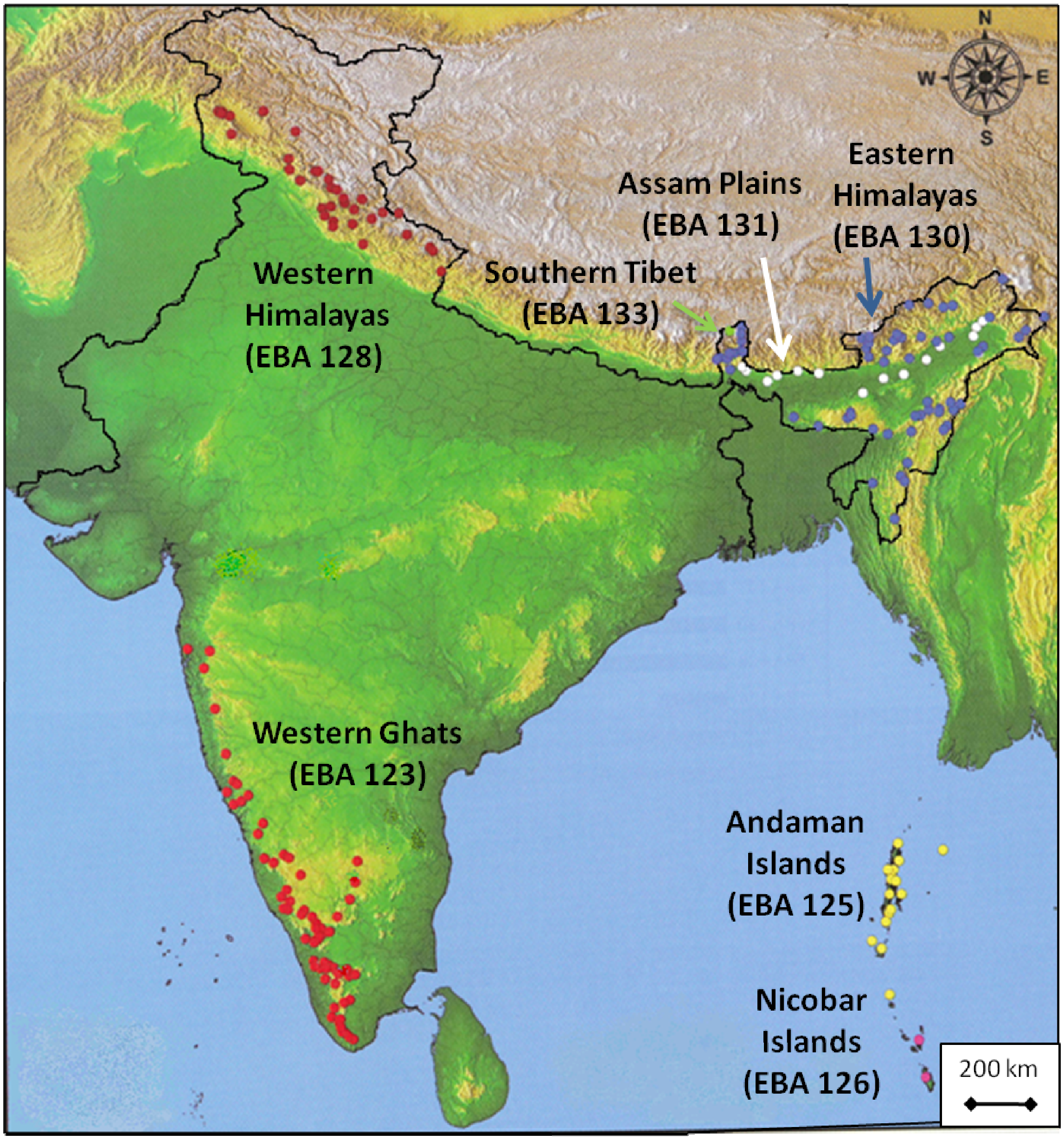

Figure 1. The seven Endemic Bird Areas of India with Important Bird Areas shown as colored dots. Map was adapted from Islam and Rahmani (2005).

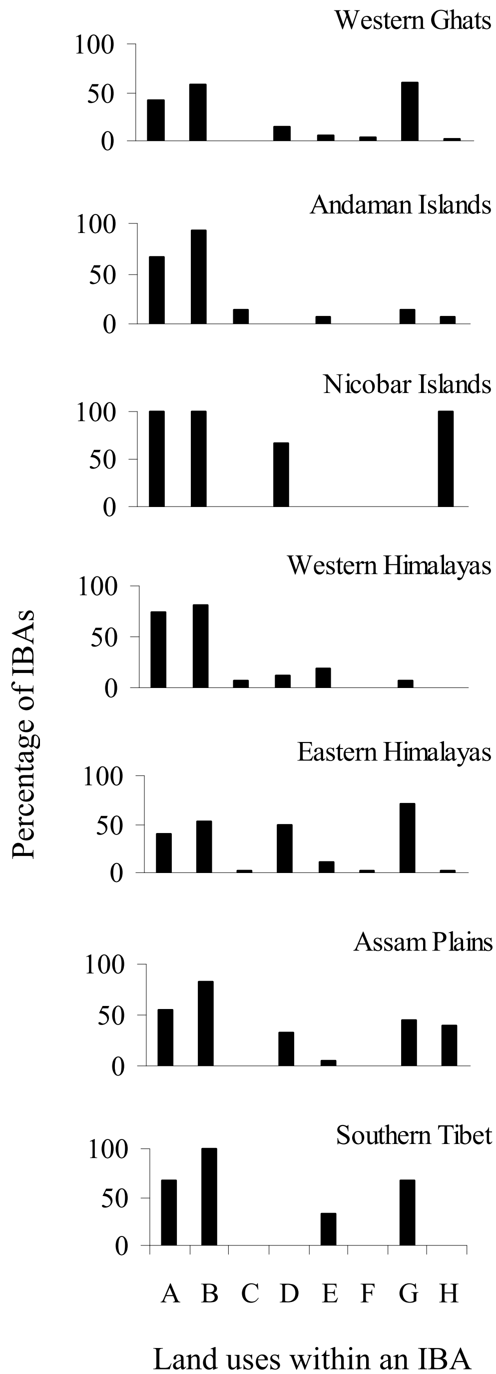

Figure 2. Percent of IBAs with a given land use. Land use indicated as follows: A - Tourism & Recreation, B - Nature Conservation, C - Tribal Reserve, D - Agriculture/Plantation, E - Water Supply, F - Dam/Power Supply, G - Forest Resources, and H – Fisheries.

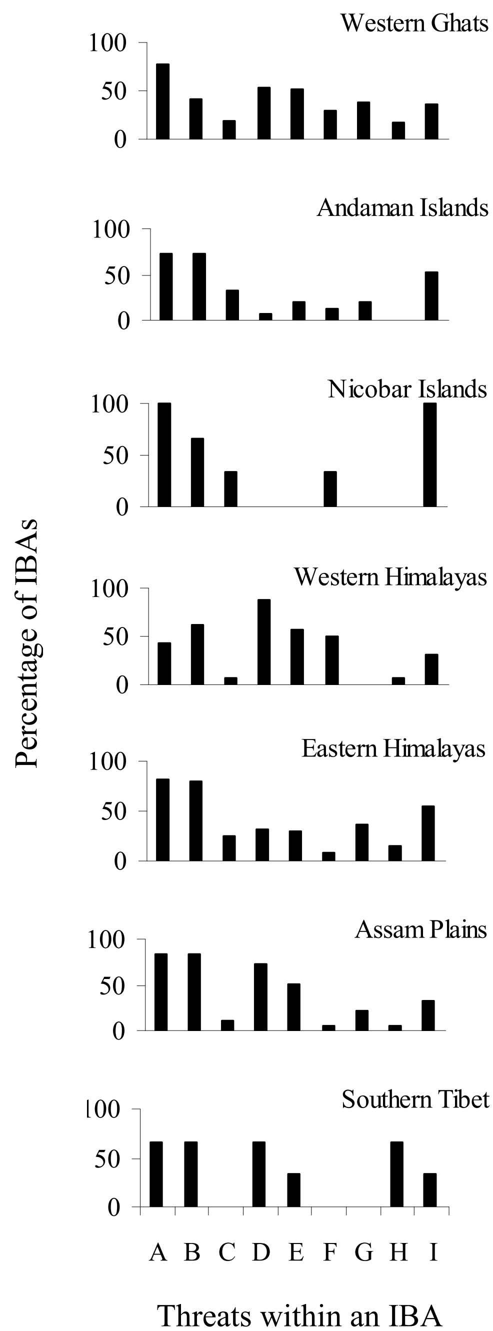

Figure 3. Percent of IBAs with a given threat. Threat indicated as follows: A - Habitat destruction, B - Poaching, C - Unsustainable exploitation, D - Grazing, E - Firewood/NTFP collection, F - Tourism/Traffic, G - Agriculture/Plantation, H - Pollution/Pesticides, and I - Industry/Development.

Appendix 1: Endemic Birds of India

#	Scientific Name	Common Name	Family	IUCN Category*	EBA
1	Spilornis klossi	Nicobar Serpent Eagle	Accipitridae	NT	126
2	Spilornis elgini	Andaman Serpernt Eagle	Accipitridae	NT	125
3	Accipiter butleri	Nicobar Sparrowhawk	Accipitridae	VU	126
4	Megapodius nicobariensis	Nicobar Megapode/Scrubfowl	Megapodiidae	VU	125, 126
5	Perdicula manipurensis	Manipur Bush Quail	Phasianidae	VU	131
6	Arborophila mandellii	Red-breasted Hill/Chestnut-breasted Partridge	Phasianidae	VU	130
7	Ophrysia superciliosa	Himalayan Quail	Phasianidae	CR	128
8	Tragopan melanocephalus	Western Tragopan	Phasianidae	VU	128
9	Tragopan blythii	Blyth's Tragopan	Phasianidae	VU	130
10	Lophophorus sclateri	Sclater's Monal	Phasianidae	VU	130
11	Catreus wallichii	Cheer Pheasant	Phasianidae	VU	128
12	Rallina canningi	Andaman Crake	Rallidae	DD	125
13	Columba elphinstonii	Nilgiri Wood Pigeon	Columbidae	VU	123
14	Columba palumboides	Andaman Wood Pigeon	Columbidae	NT	125, 126
15	Macropygia rufipennis	Andaman Cuckoo Dove	Columbidae	NT	125, 126
16	Psittacula columboides	Blue-winged Parakeet	Psittacidae	LC	123
17	Psittacula caniceps	Nicobar Parakeet	Psittacidae	NT	126
18	Centropus andamanensis	Andaman Coucal	Cuculidae	LC	125
19	Otus balli	Andaman Scops Owl	Strigidae	NT	125
20	Ninox affinis	Andaman Hawk Owl	Strigidae	NT	125, 126
21	Apus acuticauda	Dark-rumped Swift	Apodidae	VU	130
22	Harpactes wardi	Ward's Trogon	Trogonidae	NT	130
23	Ocyceros griseus	Malabar Grey Hornbill	Bucerotidae	LC	123
24	Aceros narcondami	Narcondam Hornbill	Bucerotidae	EN	125
25	Dryocopus hodgei	Andaman Black Woodpecker	Picidae	NT	125
26	Anthus nilghiriensis	Nilgiri Pipit	Motacillidae	NT	123
27	Pycnonotus priocephalus	Grey Headed Bulbul	Pycnonotidae	LC	123
28	Hypsipetes nicobariensis	Nicobar Bulbul	Pycnonotidae	VU	126
29	Brachypteryx hyperythra	Rusty-bellied Shortwing	Turdidae	VU	130
30	Brachypteryx major	White-bellied Shortwing	Turdidae	VU	123
31	Garrulax delesserti	Wynaad Laughingthrush	Timaliidae	LC	123
32	Garrulax cachinnans	Nilgiri Laughingthrush	Timaliidae	EN	123
33	Garrulax jerdoni	Grey-breasted Laughingthrush	Timaliidae	NT	123
34	Garrulax virgatus	Striped Laughingthrush	Timaliidae	LC	130
35	Garrulax austeni	Brown-capped Laughingthrush	Timaliidae	LC	130
36	Pellorneum palustre	Marsh Babbler	Timaliidae	VU	131
37	Spelaeornis caudatus	Rufous-throated Wren Babbler	Timaliidae	NT	130
38	Spelaeornis badeigularis	Rusty-throated Wren Babbler	Timaliidae	VU	130
39	Spelaeornis longicaudatus	Tawny-breasted Wren Babbler	Timaliidae	VU	130
40	Sphenocichla humei	Wedge-billed Wren Babbler	Timaliidae	NT	130
41	Stachyris oglei	Austen's/Snowy-throated Babbler	Timaliidae	VU	130
42	Turdoides subrufa	Indian Rufous Babbler	Timaliidae	LC	123
43	Babax waddelli	Giant Babax	Timaliidae	NT	133
44	Actinodura nipalensis	Hoary-throated Barwing	Timaliidae	LC	130
45	Actinodura waldeni	Austen's/Streak-throated Barwing	Timaliidae	LC	130
46	Alcippe ludlowi	Brown-throated Tit-babbler/Ludlow's Fulvetta	Timaliidae	LC	130
47	Heterophasia gracilis	Grey Sibia	Timaliidae	LC	130
48	Heterophasia pulchella	Beautiful Sibia	Timaliidae	LC	130
49	Yuhina bakeri	White-naped Yuhina	Timaliidae	LC	130
50	Paradoxornis flavirostris	Black-breasted Parrotbill	Sylviidae	VU	131

Appendix 1 (contd.): Endemic Birds of India

#	Scientific Name	Common Name	Family	IUCN Category*	EBA
51	Phylloscopus subviridis	Brooke's Leaf Warbler	Sylviidae	LC	128
52	Phylloscopus tytleri	Tytler's Leaf Warbler	Phylloscopidae	NT	128
53	Phylloscopus cantator	Black-browed Leaf / Yellow-vented Warbler	Phylloscopidae	LC	130
54	Tickellia hodgsoni	Broad-billed Flycatcher/Warbler	Cettiidae	LC	130
55	Schoenicola platyura	Broad-tailed Grassbird	Sylviidae	VU	123
56	Ficedula subrubra	Kashmir Flycatcher	Muscicapidae	VU	128
57	Ficedula nigrorufa	Black-and-Orange Flycatcher	Muscicapidae	NT	123
58	Eumyias albicaudata	Nilgiri Flycatcher	Muscicapidae	NT	123
59	Cyornis pallipes	White-bellied Blue Flycatcher	Muscicapidae	LC	123
60	Aegithalos leucogenys	White-cheeked Tit	Aegithalidae	LC	128
61	Aegithalos niveogularis	White-throated Tit	Aegithalidae	LC	128
62	Sitta cashmirensis	Kashmir Nuthatch	Sittidae	LC	128
63	Nectarinia minima	Small/Crimson-backed Sunbird	Nectariniidae	LC	123
64	Callacanthis burtoni	Spectacled Finch	Fringillidae	LC	128
65	Pyrrhula aurantiaca	Orange Bullfinch	Fringillidae	LC	128
66	Sturnus erythropygius	White-headed Starling	Sturnidae	LC	125, 126
67	Dicrurus andamanensis	Andaman Drongo	Dicruridae	NT	125
68	Dendrocitta leucogastra	White-bellied Treepie	Corvidae	LC	123
69	Dendrocitta bayleyi	Andaman Treepie	Corvidae	NT	125
70	Rhinoptilus bitorquatus	Jerdon’s Courser	Glareolidae	CR	SA**
71	Heteroglaux blewitti	Forest Owlet	Strigidae	CR	SA**
72	Pycnonotus xantholaemus	Yellow-throated bulbul	Pycnonotidae	VU	SA**
73	Garrulax nuchalis	Chestnut-backed Laughingthrush	Timaliidae	NT	SA**
74	Passer pyrrhonotus	Sind Sparrow	Passeridae	LC	SA**

*IUCN Category: CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, DD: Data Deficient

**SA: Secondary Areas are those that have only one restricted range species. This research project includes only Endemic Bird Areas (which hold at least two endemic species of birds), and does not include Secondary Areas.

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