



Complex Small-Holder Agriculture in Rainforest Buffer Zone, Sri Lanka, Supports Endemic Birds

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The Sinharaja rainforest in southwestern Sri Lanka is a protected forest in a largely agriculture-dominated landscape. In keeping with global UNESCO global biosphere reserves planning, the Sinharaja is surrounded by a buffer zone of regenerating forest and villages with small tea plots and multi-strata tree gardens (homegardens). Globally, however, conservation planning lacks standards on buffer zone management. We ask what relationships exist between village land use and bird assemblages, which are effective ecosystem indicators. Birds have been little studied across land use and vegetation structure in actively managed, large, protected forest buffer zones. To that end, we ran spatially- and temporally-replicated bird point counts across tree gardens, forest fragments, and tea plots within a Sinharaja village. Tree gardens held a greater abundance of birds across habitat association, conservation concern, diet, and endemic species than forest fragments or tea plots. Forest fragments and tree gardens hosted statistically similar numbers of birds in some subsets, but their species assemblages differed. In tea plots, greater shade tree species richness correlated with greater bird abundance and species richness. Our results support the argument for programs to support complex small-scale tree-based agroforestry embedded in buffer zone regenerating forest.

Keywords: agroforestry, tree garden, forest fragment, homegarden, rainforest, Sinharaja, tea, buffer zone

INTRODUCTION

Geological isolation and varied climate and topography produced the unique species assemblages of Sri Lanka, as in other parts of south Asia (Ripley and Beehler, 1990; Bossuyt, 2004; Kaluthota and Kotagama, 2005; Kotagama et al., 2006; Sodhi et al., 2009; Wikramanayake and Buthpitiya, 2017). In combination with the western Ghats of India, the island comprises a biodiversity hotspot with high endemism across taxa (Gunawardene et al., 2007). Twenty-seven of Sri Lanka's observed birds are confirmed endemic and an additional six are proposed endemic (Warakagoda et al., 2013; Iucn., 2016). However, formerly largely forested, Sri Lanka has lost half its forest cover since 1930 (Naresa., 1991; Reddy et al., 2018). The loss in keeping with that of much of South Asia, which lost almost 30% of forest cover in the same period (Reddy et al., 2018). Reflecting Sri Lanka's large-scale forest cover and habitat loss, seventeen of the island's endemic birds are vulnerable, near threatened, or endangered (Warakagoda et al., 2013; Iucn., 2016; Abeyarama and Seneviratne, 2017). The Sinharaja rainforest, a National Park, UNESCO Man and the Biosphere Reserve, UNESCO World

Heritage Site, and a Bird Life International Important Bird Area (IBA) in the southwest wet zone of Sri Lanka, is one of the only remaining stretches of relatively undisturbed, connected, lowland rainforest on the island (Gunatilleke et al., 2005). It contains significant avian phylogenetic diversity (Abeyarama and Seneviratne, 2017). In a nation of great climate and topographic heterogeneity, the Sinharaja lowland rainforest is particularly important to preserving Sri Lanka's biodiversity, including avifauna (Gunatilleke and Gunatilleke, 1983; Gunatilleke et al., 2017).

Consistent with UNESCO's global biosphere reserves organization, a buffer zone surrounds the Sinharaja rainforest (Unesco., 1996). Forest reserve buffer zones can help maintain local ecology (Robinson et al., 2013). However, there is a lack of global consensus on buffer zone management (Margles et al., 2010; Allan et al., 2017).

The Sinharaja's buffer consists of regenerating forest and forest villages, which comprise homes, small tea plots, and multi-strata tree gardens (homegardens) (Wijesooriya and Gunatilleke, 2003; Dewi et al., 2013). Tree gardens reflect a system of indigenous tree culture common throughout South and Southeast Asia that is ancient but still evolving (Kumar and Nair, 2006; Martin et al., 2018). They provide medicine, food, construction material, fuel, fodder, and income to residents across the tropics from rural to urban settings. Tree gardens contribute to food security and local economies (Jaman et al., 2016; Sangakkara and Frossard, 2016; Paembonan et al., 2018; Rousta et al., 2018; Park et al., 2019). They are managed for resilience to climate and economic changes (Weerahewa et al., 2012). Tree gardens help maintain local and regional biodiversity through the tropics (Watson and Eyzaguirre, 2002; Kumar and Nair, 2006; Galluzzi et al., 2010; Kumar and Nair, 2011; Schroth et al., 2013), with specific research from Sri Lanka (Mohri et al., 2013), Indonesia (Michon et al., 1986; Mohri et al., 2013), Vietnam (Trinh et al., 2003; Mohri et al., 2013), Thailand (Timsuksai and Rambo, 2016), Malaysia (Moore et al., 2016), India (Das and Das, 2015), and Brazil (Peroni et al., 2016). In Sri Lanka, tree gardens make up almost half of total forest area and fourteen percent of the country's total land area (Mattsson et al., 2013; Reddy et al., 2018). Research from 2010 estimated that they comprised one fifth of the country's aboveground carbon stocks (Mattsson et al., 2013). They are actively supported by government policies (Fao., 2009; Pushpakumara et al., 2012; Chokkalingam and Vanniarachchy, 2013; Galhena et al., 2013; Mattsson et al., 2017). Understanding how and to what ends they contribute to conservation goals is necessary.

We studied bird use of a Sinharaja buffer zone village and its tree gardens. Birds provide ecological, economic, and scientific value, all of which make them important research subjects. The ecosystem services they provide include pollination, seed dispersal, and insect control (Sekercioglu, 2006). Bird-tourism is a significant and growing part of global eco-tourism, and draws foreign visitors specifically to the Sinharaja (Sekercioglu, 2002; Goodale et al., 2014; Arachchi, 2020). Birds are also effective ecosystem indicators across landscapes (Macarthur, 1964; O'Connell et al., 2000; Sekercioglu et al., 2004). Previous studies of bird populations in intensively managed tropical

landscapes compared other agroforestry systems to intact forest (Thiollay, 1995; Perfecto et al., 1996; Calvo and Blake, 1998; Mas and Dietsch, 2004; Waltert et al., 2004; Beukema et al., 2007; Harvey and Villalobos, 2007; Van Bael et al., 2007; Tschardt et al., 2008; Clough et al., 2009; Sekercioglu, 2012). Others examined tree gardens, agroforestry systems, and regenerating forest, but few did so in small-scale land use areas within the buffer zone of a large, undisturbed, conservation area (Sidhu et al., 2010; Kottawa-Arachchi and Gamage, 2015; Engelen et al., 2016; Prabowo et al., 2016; Perera et al., 2017). Yet tree gardens in buffer zones contain plants that provide food and shelter for birds (Martin et al., 2018). There is a need to quantify how the structure and size of buffer zone land use translates to bird presence around the Sinharaja (Waltert et al., 2011; Goodale et al., 2014).

To that end, we quantified the bird assemblages observed in small-scale tree gardens, forest fragments, and tea plots within the buffer zone village. We asked: (1) How does bird assemblage vary with land use? (2) Are there relationships between vegetation characteristics and bird assemblages? (3) What land use type hosts the greatest number of multi-species flocks?

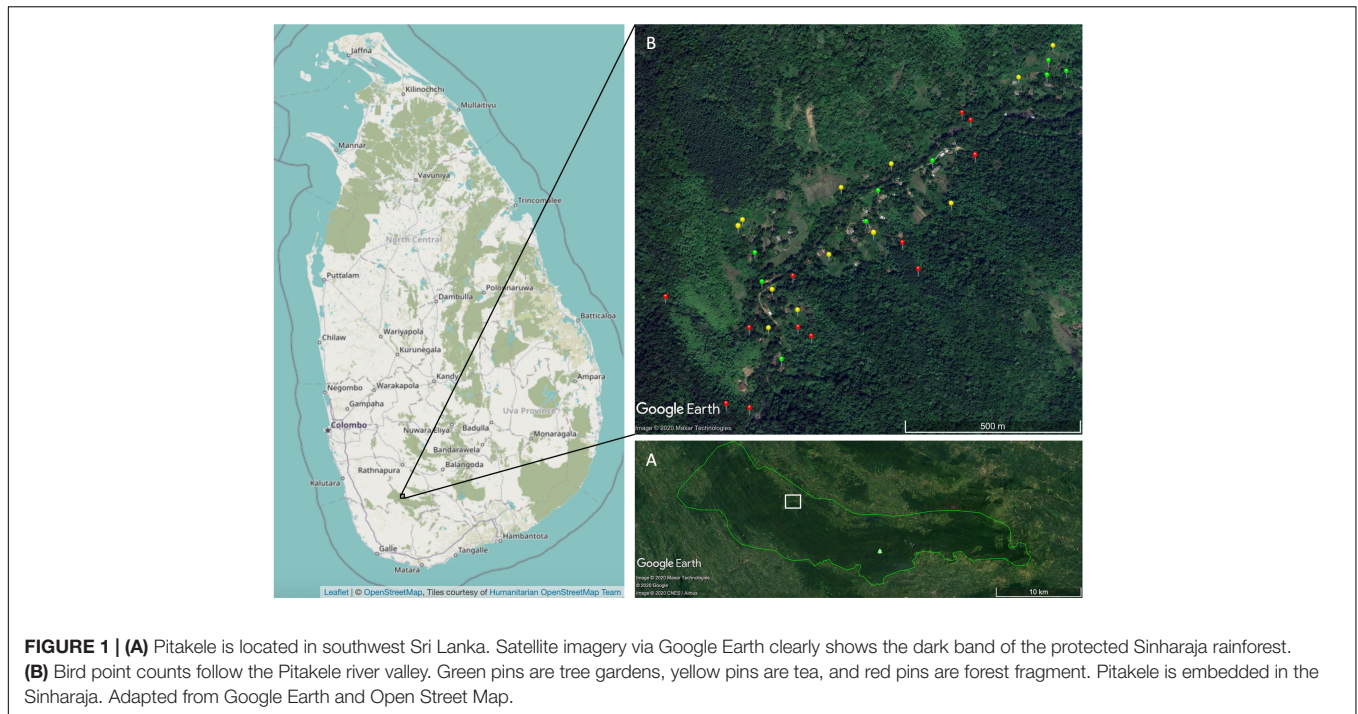
Research suggests that the greater a habitat's complexity, the greater the complexity of its species assemblage (Macarthur, 1964; Roth, 1976). We expected to see that tree gardens would host larger and more complex species assemblages than tea plots. We expected more complex vegetation would host more complex bird assemblages. Since multi-species flocks are a documented forest phenomenon, we expected to see more flocks in forest fragments (Goodale et al., 2014).

MATERIALS AND METHODS

Study Site

Pitakele village is a community of thirty-plus households bordering the core of the Sinharaja Forest Reserve (6°26'N 80°21'E, 300–700 m in altitude), at the end of a jungle road in the northwest of the reserve's buffer zone (**Figure 1**). It receives an average annual rainfall of 3 m with a dry season from January to March (Munidasana et al., 2002). The region's average daily temperatures vary between 22 and 28°C (Ashton et al., 2001; Gunatilleke et al., 2005).

Like other rainforest-embedded villages in Sri Lanka, the homes of Pitakele lie along and upslope of a river, surrounded by tree gardens and often downslope of cultivated tea. Tea plots comprise 39% village land area, tree gardens comprise 27%, and forest fragments comprise 17% (Martin et al., 2018; **Figure 1**). Tea plots in Pitakele include shade trees, typically *Gliricidia sepium*, but also kitul (*Caryota urens*), other palms, and rainforest or cultivated tree garden species. Tea (*Camellia sinensis*) land borders second-growth rainforest, which was logged in the 1970s, or rubber (*Hevea brasiliensis*) or Caribbean pine (*Pinus carribea*) plantings (Kotagama and Goodale, 2004). The primary source of income for many Pitakele villagers is from picking tea. The village tree gardens average 0.12 ha in size with a mean species richness of 64 trees, shrubs, herbs, and climbers (Martin et al., 2018). At least 219 different species are grown across Pitakele's homegardens (Martin et al., 2018). The overstories of these tree



gardens are dominated by betel palm (*Areca catechu*), coconut (*Cocos nucifera*), and kitul palm (*Caryota urens*); lower strata by mango (*Mangifera indica*) and jack (*Artocarpus heterophyllus*) (Martin et al., 2018). Secondary forest fragments lie on rocky ground close to the river or steep slopes less favorable for growing crops. They average 0.12 ha in size (Martin et al., 2018). Some forest fragments connect to the Sinharaja's core reserve. Our study area is approximately 100 ha. Pitakele village is representative of settlements that about the whole Sinharaja (Figure 1).

Sampling Design

We conducted thirty-three 20 m-radius bird point counts, with nine point counts in tree gardens, 12 in tea plots, and 12 in forest fragments. We recorded all birds seen and heard within a plot, including birds in flight, for 30 min (since it is a relatively small point count plot and flock observations can last for 10–60 min after first observation) (Farley et al., 2008). Other point counts within Sri Lanka have been conducted using the variable circular plot method (Wijesundara and Wijesundara, 2014). Previous studies within the Sinharaja buffer zone have been run along transects (Kotagama and Goodale, 2004). We used point counts to account for small-scale differences in land use. Bird point counts are non-invasive.

We ran each point count five times between January and March 2018. No plot was closer to the edge of the land use area than 20 m, the radius of the plot. We visited each site between 7:00 and 10:30 a.m. For every bird, we noted if they were part of a multi-species flock, i.e., moving with birds of other species in a close association. We conducted the point counts over the dry season, when winter migrants are present and many resident species breed (Jayarathna et al., 2013). We did not sample on

mornings when it rained and randomized dates and times of the site visits.

Vegetation Surveys

We counted all trees within 10 m of the point count plot center and measured their diameter at breast height. We measured the total tree species richness of the plots, counting trees per species. We measured tree basal area from the center of the plot by using an angle gauge (metric basal area factor 2.5) in a variable radius plot, a standard forestry method (Packard and Radtke, 2007).

Analysis

For all variables, we calculated Moran's I tests. Where Moran's I test ruled out spatial autocorrelation, we ran further analyses. We tested all variables for normal distribution using the Shapiro-Wilks test ($p > 0.05$).

To answer how bird assemblage varied with land use, we analyzed point count data by total bird abundance, richness, and diversity; habitat association, conservation significance, and diet; and endemic species. Assemblage subsets by habitat association and diet reflect functional relationships between birds and habitat. Conservation significance shows if and how the landscape contributes to conservation goals. We looked at individual endemic species because Sri Lanka and the Sinharaja are important for endemic species. These subsets are commonly tested and can be used for cross-study comparison (Tscharntke et al., 2008; Maas et al., 2009; De Lima et al., 2012; Sekercioglu, 2012; Goodale et al., 2014). We tested species assemblage via multivariate analyses of variance (MANOVA).

We adopted habitat classifications (forest, open landscape, or both) from Goodale et al. (2014), which based its identifications on Ali and Ripley (1987) and Grimmett et al. (1999). Where

bird-habitat associations were not identified by Goodale et al. (2014), we used Warakagoda et al. (2013) to classify them. We classified birds as of conservation concern if they were listed as “Near Threatened,” “Vulnerable,” or “Endangered” by the 2016 IUCN Red List. All of the birds identified as of conservation concern are declining in number (IUCN, 2016). We grouped birds by diet (frugivorous, nectarivorous, insectivorous, granivorous, or carnivorous) following Goodale et al. (2014), who used Rasmussen and Anderton (2012). We tested each subset’s mean abundance per plot. We tested mean endemic species richness per plot. We tested the mean abundance of individual endemic species observed at least three times. On normally distributed variables we ran analysis of variance (ANOVA) by land use type. If significant, we then ran a Tukey *post hoc* test. On non-normally distributed variables, we ran a Kruskal-Wallis test with a Bonferroni correction. We tested species assemblage variation per land use type by running three pair-wise MANOVAs of total bird species abundance and endemic bird species abundance. We square-root transformed the data for both MANOVAs to minimize the influence of the most common species. We used Bray-Curtis distance, 999 permutations, and a Bonferroni correction with $\alpha = 0.05$. We ran a non-metric multidimensional scaling (NMDS) analysis (Figure 3) to visualize differences.

To answer question 2, whether bird assemblages varied with vegetation characteristics, we ran generalized linear regressions on total bird abundance, bird species richness, and abundance of conservation concern species by basal area measured by variable radius plot, and basal area, stem density, and tree species richness within 10 m of plot center. We used Gaussian distributions. To test for land use-specific correlations, we subdivided the data by land use. We ran GLMs by land use separately because other studies have observed that relationships between birds and vegetation characteristics can vary with type of habitat (Duguid et al., 2016). We ran ANOVA with Tukey *post hoc* analysis or Kruskal-Wallis with Bonferroni correction to check how basal area, tree species richness, and stem density varied with land use.

To answer question 3, what land use type hosted the greatest number of multi-species bird flocks, we analyzed flock presence, or the mean number of flocks observed in a plot, and flock size, the mean number of birds in a plot that were part of a flock. We ran the Kruskal-Wallis test with a Bonferroni correction on both variables, which were non-normally distributed.

RESULTS

We observed 1,269 individual birds of 76 species across the 33 plots. We observed 59 species in tree gardens, 48 species in forest fragments, and 44 species in tea plots. We observed 17 endemic species.

Assemblage Variation

Bird abundance and Shannon-Weiner diversity were higher in tree gardens than in forest fragments or tea plots (Figure 2) [$F_{(2,30)} = 20.79, p < 0.001$] (Kruskal-Wallis chi-square = 16.39, $df = 2, p < 0.001$); and bird species richness was higher in forest fragments than in tea plots [$F_{(2,30)} = 22.16, p < 0.001$].

Birds associated with both open lands and forest, endemic birds, frugivorous birds, and nectarivorous birds (only the purple-rumped sunbird, *Leptocoma zeylonica*) were observed in higher abundances in tree gardens than in either forest fragments or tea plots (Table 1). Forest-associated birds and insectivorous birds were more abundant in both tree gardens and forest fragments than in tea plots (Table 1). Species of conservation concern were more abundant in tree gardens than in tea plots, and their numbers in forest fragments statistically overlapped both (Table 1). Similarly, endemic bird species richness was greater in tree gardens than in tea plots and their numbers in forest fragments statistically overlapped both (Table 1). Open land-associated birds were more abundant in tree gardens than in forest fragments, and their abundance in tea plots statistically overlapped both (Table 1). Carnivorous birds did not vary across land use type.

MANOVA analysis showed that bird composition differed between land use [$F_{(2,30)} = 5.22, p < 0.001, r^2 = 0.26$].

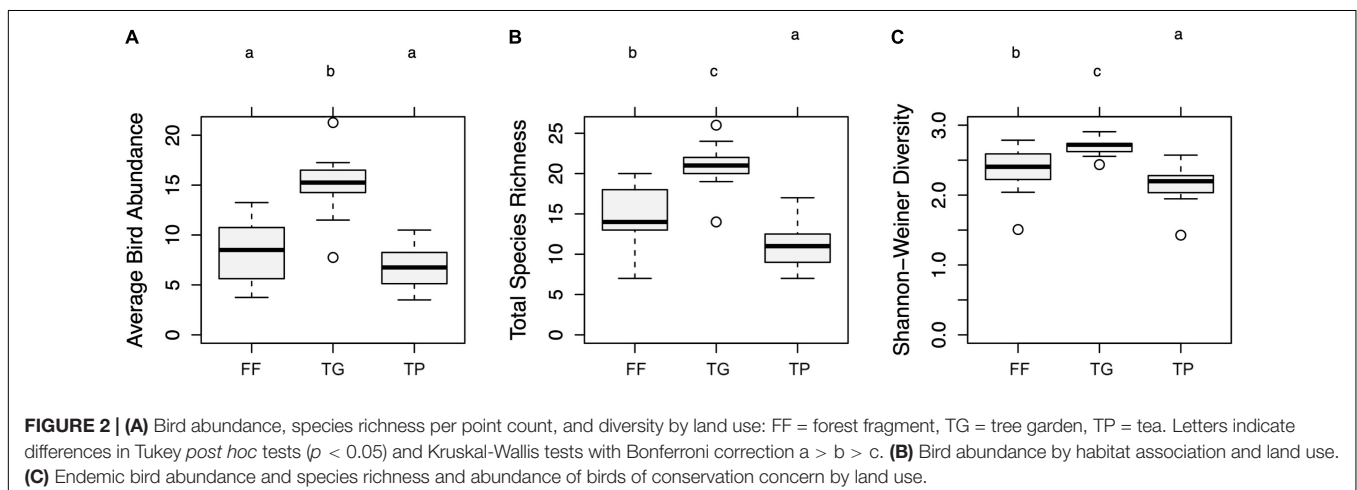


TABLE 1 | Mean abundance per point count visit of bird assemblage subsets.

Group	Number species	Forest fragment	Tree garden	Tea plot	Chi-square or <i>F</i> -test
Frugivorous	23	3.06 (1.93)^a	8.47 (2.54)^b	3.73 (1.48)^a	$F_{(2,30)} = 19.86^{***}$
Nectarivorous	1	0.69 (0.46)^a	1.72 (0.51)^b	0.88 (0.56)^a	$F_{(2,30)} = 10.44^{***}$
Granivorous	4	0.00 (0.00)	0.61 (0.55)	0.10 (0.24)	
Carnivorous	6	0.04 (0.14)	0.11 (0.17)	0.04 (0.09)	1.99
Insectivorous	42	4.73 (1.21)^b	3.97 (1.47)^b	2.00 (0.80)^a	$F_{(2,30)} = 15.88^{***}$
Forest-associated	24	16.17 (4.47)^b	17.44 (5.89)^b	8.67 (5.27)^a	$F_{(2,30)} = 8.53^{***}$
Open land-associated	18	2.17 (1.99)^a	11.33 (6.16)^b	4.83 (3.72)^{ab}	11.04^{**}
Both	34	15.75 (8.64)^a	30.78 (7.89)^b	13.5 (5.22)^a	$F_{(2,30)} = 14.62^{***}$
Endemic	17	1.67 (1.07)^a	3.00 (0.89)^b	1.44 (0.97)^a	8.67[*]
Conservation concern	8	0.88 (0.67)^{ab}	1.31 (0.74)^b	0.52 (0.65)^a	6.07[*]
Endemic species richness		3.58 (1.89)^{ab}	5.33 (1.76)^b	2.67 (1.31)^a	$F_{(2,30)} = 6.05^{**}$

Groups by diet are ordered by frequency of observation per land use. Subsets observed most often in tree gardens are listed first, then subsets observed most often in forest fragments. We highlight in gray each subset's greatest abundance per land use. Standard deviation follows abundance in parenthesis. Subsets are bolded where their variation is significant by ANOVA with Tukey post hoc test or Kruskal-Wallis test with Bonferroni correction.

Letters indicate differences in Tukey post hoc tests ($p < 0.05$) and Kruskal-Wallis tests with Bonferroni correction $a > b > c$.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Multivariate means for bird assemblages differed between forest and tree garden, [$F_{(1,19)} = 3.08$, $p = 0.001$, $r^2 = 0.17$], between tree garden and tea [$F_{(1,19)} = 3.17$, $p < 0.001$, $r^2 = 0.14$], and between forest fragment and tea plots [$F_{(1,22)} = 6.97$, $p < 0.001$, $r^2 = 0.24$] (see **Figure 3**). MANOVA analysis showed that endemic bird composition differed between land use [$F_{(2,30)} = 5.22$, $p < 0.001$, $r^2 = 0.26$]. Multivariate means for endemic bird assemblages differed between forest and tree garden [$F_{(1,19)} = 3.78$, $p = 0.003$, $r^2 = 0.17$], between tree garden and tea [$F_{(1,19)} = 2.51$, $p = 0.02$, $r^2 = 0.12$], and between remnant forest fragment and tea [$F_{(1,22)} = 2.97$, $p = 0.005$, $r^2 = 0.12$].

Of the endemic bird species that varied significantly across land use type according to ANOVA and the Tukey *post hoc* test, four species were observed most often in tree gardens and one in forest fragments (**Supplementary Table 1**).

Variation With Vegetation

Tree basal area, tree species richness, and stem density was statistically greater in forest fragments and tree gardens than in tea plots (**Table 2**).

GLMs showed significant but relatively weak correlations between bird abundance and tree species richness [$F_{(1,31)} = 5.07$, $b = 7.17$, $r^2 = 0.14$, $p = 0.03$]; and bird species richness and tree species richness [$F_{(1,31)} = 7.33$, $b = 11.72$, $r^2 = 0.19$, $p = 0.01$]. When regressions were run in subsets of land use type, bird abundance and species richness were strongly related to tree species richness in tea [$F_{(1,10)} = 16.7$, $b = 4.35$, $r^2 = 0.63$, $p = 0.002$; $F_{(1,10)} = 5.90$, $b = 8.66$, $r^2 = 0.37$, $p = 0.04$].

Flocks

Flock presence did not vary significantly with land use (**Table 2**). Flock size was higher in forest fragments than in tea plots (**Table 2**).

DISCUSSION

Across habitat association, conservation concern, and diet group, more birds and a greater variety of them used tree gardens than forest fragments or tea plots in the buffer zone village. Tree gardens hosted the most endemic species and species of conservation concern. Species assemblages differed between forest fragments, tree gardens, and tea plots. More frugivores, species associated with both forests and open lands, and endemic species were observed in tree gardens than in forest fragments or tea plots. Within tea plots, greater bird abundance and species richness correlated with greater tree species richness.

The literature shows that tree gardens can host similar amounts of birds to protected forests but lose species from their assemblages, and that bird use of agroforestry more generally is driven by proximity to protected forest. Tree gardens can host the same amount of or more birds than protected forest (Kottawa-Arachchi and Gamage, 2015; Prabowo et al., 2016). Some species observed in forest landscapes are lost in agriculture or tea (Engelen et al., 2016; Perera et al., 2017). Other studies have compared differences in bird assemblages between other agroforestry systems and forests, reporting results that vary with place and system (Thiollay, 1995; Beukema et al., 2007). For example, while one study from Sumatra, Indonesia, reported less species richness in complex agroforests than in primary forest (Thiollay, 1995), another Sumatra study in different agroforests showed little difference in bird diversity (Beukema et al., 2007). While Scales and Marsden (2008) of biodiversity change across habitats reported that small-scale agroforestry usually holds less biodiversity than retained forest, it depended on the system. In reviews, Waltert et al. (2004) and Clough et al. (2009) observed that abundance and species richness declines with monodominance and distance from intact rainforest. In single studies Anand et al. (2008) and Goodale et al. (2014) found that distance to intact rainforest had a larger effect on bird abundance and species richness than specific land use. Engelen et al. (2016) did not observe a difference in homegarden bird assemblages at

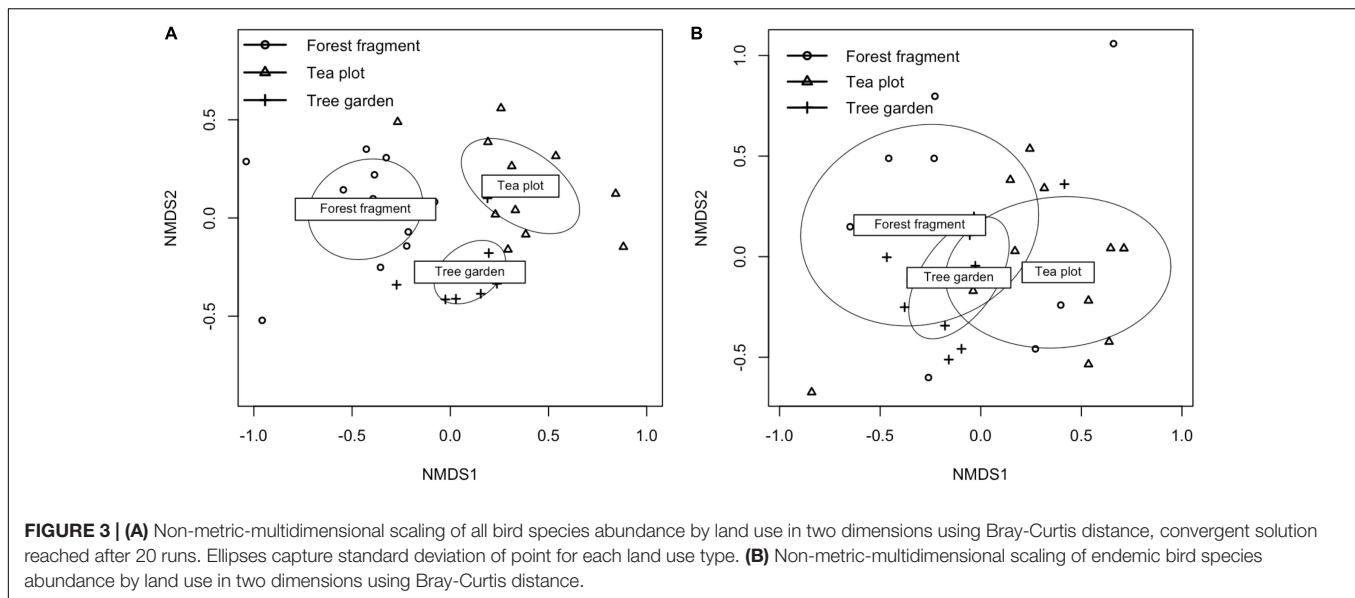


TABLE 2 | Variation of multi-species flocks and vegetation across land use types.

Variable	Forest	Tree garden	Tea	Chi-square or <i>F</i> -test
Flock presence	0.29 (0.22)	0.14 (0.12)	0.10 (0.19)	
Flock size	9.93 (3.95)^b	6.4 (3.14)^{ab}	4.6 (3.38)^a	$F_{(2,21)} = 3.954^*$
Basal area	95.83 (44.99)^b	55.56 (24.09)^b	13.33 (12.47)^a	21.648^{***}
Tree species richness	8 (2.27)^b	6.22 (2.04)^b	1.42 (0.95)^a	$F_{(2,30)} = 37.35***$
Stem density	17.92 (4.68)^b	16.11 (7.19)^b	4.42 (6.14)^a	$F_{(2,30)} = 15.93***$

Values are shaded gray in the land use where they are highest. Standard deviation follows in parenthesis. Variables are bolded where their variation is significant by ANOVA with Tukey post hoc test or Kruskal-Wallis test with Bonferroni correction.

Letters indicate differences in Tukey post hoc tests ($p < 0.05$) and Kruskal-Wallis tests with Bonferroni correction $a > b > c$.

* $p < 0.05$; *** $p < 0.001$.

different distances from protected forest. Based on this literature, Pitakele needs to be seen specifically as a buffer zone village with all plots proximate to intact forest.

Bird Abundance by Habitat Association and Diet

While tree gardens host different bird communities than forest fragments, birds of varied habitat association, including forest-associated species, use tree gardens in the buffer zone. Research from the Sinharaja and India's western Ghats found that the bird community in buffer zones outside of conserved forests retained more than 70% of forest interior species (Goodale et al., 2014). The high number of forest-associated birds in tree gardens could be due to the variety of food and shelter provided by a multi-strata tree garden (Tews et al., 2004; Perera et al., 2017). Open land-associated birds may also use these resources. Most of the tree gardens border open areas but not forest fragments. However, second-growth rainforest around the Sinharaja's core is becoming dense, entering the late stem exclusion phase of forest development which, locals observed, propels forest birds to its edges (Oliver and Larson, 1996). This may increase the use of tree gardens by forest species. Future research can further identify specific vegetation to support birds.

Flock size in Pitakele was observed to be highest in forest fragments. Goodale et al. (2014), in comparing bird flocks and communities between primary forest, pine plantations, and open agriculture, observed that flock densities in buffer areas in general were similar to those of intact primary forests, but flocks were smaller. Our results show that flocks are present in buffer zone tree gardens with fewer birds than in forest fragments. While buffer zone tree gardens host multi-species flocks, tree gardens do not replace forest fragments in bird flock use.

Tscharntke et al. (2008) and Sekercioglu (2012) report that species richness of large frugivorous and insectivorous birds decline in agroforests as compared to original primary rain forest; whereas nectarivores, small-to-medium frugivores, omnivores, and sometimes granivores and small frugivorous birds do better in agroforestry landscapes. Our results differ in that we observed statistically similar numbers of insectivores in tree gardens as forest fragments. This may be due to the closeness of Pitakele's tree gardens to intact rainforest.

Tea Shade Tree Diversity

Our results show that diversity in shade tree systems benefits bird abundance and species richness in this protected area buffer zone. More complex agroforestry systems result in more complex bird

communities (Perfecto et al., 1996; Calvo and Blake, 1998; Mas and Dietsch, 2004; Waltert et al., 2004; Harvey and Villalobos, 2007; Van Bael et al., 2007; Anand et al., 2008; Clough et al., 2009). The direct relationships between tree species richness and bird diversity and abundance within tea plots demonstrates that this principle holds true on small land use areas in the conservation buffer zone.

Endemic Birds

Endemism is globally high on islands, where biodiversity is at high risk (Scharlemann et al., 2004; Ricketts et al., 2005; Kier et al., 2009). Agriculture has disproportionately expanded in Endemic Bird Areas (Scharlemann et al., 2004). Studies show that endemic birds decrease with the intensity of land use in human-modified tropical landscapes (Maas et al., 2009; Waltert et al., 2011; De Lima et al., 2012; Davies et al., 2015). Tropical forest conversion to farmland can result in the replacement of endemics by widespread species (Maas et al., 2009; Waltert et al., 2011; Dallimer et al., 2012; De Lima et al., 2012; Sekercioglu, 2012).

We observed endemics in greater abundance within tree gardens than in the other land uses and in greater species richness in tree gardens than in tea plots. The Sri Lanka gray hornbill (*Ocyrceros gingalensis*), and the Sri Lanka junglefowl (*Gallus lafayetii*) were observed significantly more in tree gardens than in tea plots or forest fragments. The white-throated flowerpecker (near threatened, *Dicaeum vincens*) was observed significantly more in tree gardens than in tea plots, with statistically intermediate values in forest fragments. The Sri Lanka hanging parrot (*Loriculus beryllinus*) was observed significantly more in tree gardens and tea plots than forest fragments. We observed five other endemics most often in tree gardens without statistical significance (**Supplementary Table 1**). The endemic, vulnerable red-faced malkoha (*Phaenicophaeus pyrrhocephalus*) was observed only in forest fragments. We note that while Perera et al. (2017), who also examined birds in a SW Sri Lankan forest buffer zone, did not observe forest endemics in buffer zone tree gardens, their study included tea plots as tree garden, had only five of these plots, and ran their point counts outside a smaller protected area. A Sri Lanka-wide survey of birds observed half the number of endemic species in tree gardens across the country as this study (Bambaradeniya, 2003). Since most of this study's observed endemics are forest-associated birds, this data is buffer-zone specific. Waltert et al. (2011) observed correlations between endemic species richness in agroforestry with tree abundance and tree species richness. We suggest that habitat diversity may contribute to Pitakele tree gardens hosting endemic bird species. Our results and the literature suggest that endemic birds are present in the buffer zone tree gardens due to proximity to the large protected area and tree garden habitat complexity. We do not suggest that individual land uses support entire species or subsets. The complete buffer zone matrix and extensive edge habitat available in the village buffer define these habitats.

Management Implications

Tropical reserve systems are often encroached. Successful conservation depends on buffer land cover that is also

profitable for residents—but conservation planning lacks global standards on buffer zone management (Budhathoki, 2004; Margles et al., 2010; Waltert et al., 2011; Dewi et al., 2013; Robinson et al., 2013; Goodale et al., 2014; Lui and Coomes, 2016; Allan et al., 2017). Programs like the EU's Small Grants Program for Operations to Promote Tropical Forests Program have focused on developing resilient and self-supporting communities within tropical conservation buffer zones (RECOFTC., 2008; Rands et al., 2010). Agroforestry can integrate forests in a multifunctional landscape for conservation, including specifically in the Sinharaja (Michon et al., 1986; Bhagwat et al., 2008; Jose, 2009; Dewi et al., 2013; Kothalawala et al., 2013). Complex cover benefits birds. This study shows that programs for tree garden agroforestry in buffer zones like that of the Sinharaja can support habitat for vulnerable and endemic birds, including forest-associated ones. However, tree gardens do not replace forest fragments or protected core forest. We suggest pursuing further research on the ecological significance of tree gardens broadly in tropical protected area buffer zones.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MA conceived the study. MA, BS, and JH planned methodology. MA and JH planned analyses. JH collected the data, and analyzed and wrote the manuscript with input from MA and BS. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2021.608434/full#supplementary-material>

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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