Diversity of Bird Communities in Tea (*Camellia sinensis*) Plantations in Fujian Province, South-Eastern China

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Abstract: Habitat conversion in mountain areas threatens their biodiversity. The effect on biodiversity of creating a mountain landscape with a network of forest fragments and a cultivated habitat matrix is poorly documented in China. Bird communities in forest fragments and tea plantations were censused by field observations in two years (2018–2019) in three tea-growing locations, Anxi, Beifeng, and Wuyishan in Fujian Province, south-eastern China. Out of a potential pool of 247 forest-associated bird species, we detected the presence of 82, mostly resident species, 32–47 of those regularly visiting tea plantations. Species-accumulation curves indicated the near-completeness of the census. The Rényi diversity profiles indicated a more diverse community in forest fragments than nearby tea plantations at Anxi and Beifeng, but the tea plantations at Wuyishan supported a more diverse bird community than the forest. Avian communities in tea plantations were a significantly nested subset of the forest communities. Tea plantations can provide resources for forest-associated birds, but the effectiveness of preserving avian diversity depends on natural forest fragments and can be enhanced by landscape-scale management, when the biocontrol potential of birds can also be enhanced.

Keywords: agroforestry; avian diversity; bird census; forest fragmentation; nestedness

1. Introduction

Human domination of the biosphere is reflected in many parameters, among them the >50% conversion of the original habitats to cultivated fields [1]. These habitats, while often poorer in diversity than the original ones they replaced [2], still can sustain important components of biodiversity, and cannot be discounted as "biological deserts". During conversion, the originally dominant (matrix) habitat becomes reduced in area as well as fragmented, while the cultivated areas become the new matrix. While fragmentation in itself may not be detrimental [3], it is often accompanied by habitat area reduction, which has well-documented negative impacts on biodiversity [4]. The resulting mosaic-like cultivated landscape has large variability in the amount of original habitat left, the size, distribution, and configuration of the remaining fragments, as well as in the frequency/severity of disturbance.

The role of these nonconverted habitat fragments in conserving biodiversity is a subject of intensive research as well as discussion [5]. We do not yet have a comprehensive understanding of the governing principles of this "countryside biodiversity" [6], namely just how much of the original biodiversity can be saved, which components of it can use the new landscape, and to what degree. What level of biodiversity remains in such a cultivation-dominated landscape remains an open question in many parts of the world, with fragmentary documentation of the resulting changes, even for otherwise reasonably well-known groups like birds. Answering that question has urgency because of the accelerating changes and continuing habitat conversion, but also because of attempts and suggestions to implement an "ecological intensification" [7] in order to make agriculture more productive but sustainable. Ecological intensification considers elements of biodiversity that are useful as providers of ecosystem service (ES) as ones to be favoured and supported. Even though birds are recognised as important providers of several ESs [8], there can be a possible clash between the goals of biodiversity protection and ecological intensification, especially in regions where the original habitats have been substantially modified.

China, especially in the coastal areas and large river basins has been inhabited for millennia, and the original natural habitats have been profoundly transformed [9]. The country is the largest producer of tea (*Camellia sinensis* (L.) Kuntze), which was domesticated in China, and has been grown for millennia for its stimulant effects [10,11]. Being a perennial plant of which only small parts of the fresh growth are plucked, plantations of tea do not experience periodical destruction during harvest and in comparison with annual crops, can be considered a relatively complex and stable environment with the potential to support high biodiversity. Tea originally is a forest tree, although now mostly cultivated as a short-pruned shrub [12]. The overwhelming majority of current tea gardens occupy the areas of former forests; this conversion has left smaller or larger forested patches and tree shelterbelts in a landscape 'matrix' of tea plantations in China as well as elsewhere [11]. Consequently, the role of the remaining fragments as well as of the new matrix in maintaining biodiversity, a vigorous research topic in other parts of the world [13] is a relevant approach in this context. Biodiversity in such transformed landscapes has an obvious source: the original habitat. Not all species living there can tolerate the new conditions, thus the biodiversity on the converted areas can be a nested subset of that in the original habitat [14]. Theoretically, it is possible that none of the species from the original habitat can survive in the converted one, thus the species found in the latter are all immigrants from elsewhere. The degree of nestedness can be useful to point to assembly rules that created the biodiversity of the new landscape [15].

Birds are taxonomically well-known and also constitute a flagship group for conservation. China, with its 1300+ species, is a country with a high diversity of birds, especially in the south [16]. Previous studies of forest birds in the south of China detected >110 species in traditionally managed forests [17] or 80 species in protected ones [18]. Agroforestry [19] and shade-grown coffee [20] or cocoa [21] can support several forest-based bird species in Asia, and Central–South America. The avifauna related to tea plantations is less well studied. A survey in Anhui Province undertaken 35 years ago [22] documented the presence of 24 bird species on tea plantations, and reviews of all natural enemies mention 42 bird species [23,24]. Overall, the bird community so far documented is not species-rich, although the focus of the studies was not at the landscape scale. In India, another major tea-growing country as well as a bird diversity hotspot, a census in tea gardens in Assam recorded the presence of 123 bird species, 15% of which were specific to this habitat [19], while Sinu [25] and Chettri et al. [26] found only 38 and 48 species, respectively. At the Rosekandy Tea Estate of Assam, there are 88 species during winter, 60 of which occur in secondary forest, and 48 on tea plantations [27]. In a tea-growing landscape in the Western Ghats, southern India, during the dry season, 30 species are present in the undisturbed forest and 31 in the forest fragments [28]. Some of the species recorded in India are either protected species or seasonal migrants, proving that tea plantations can provide valuable habitat and resources for birds.

In this study, our aim was to document changes in bird community composition between forest and tea plantations in a tea-cultivating landscape in a mountainous province of China. We tested the following hypotheses:

Hypothesis 1. *Bird assemblages found in forest fragments will be an impoverished subset of the potential forest avifauna.*

Hypothesis 2. *The diversity of bird assemblages will be higher in the forest fragments than on tea plantations.*

Hypothesis 3. *The birds detected on tea plantations will be a nested subset of the bird assemblage of the forest fragments.*

During our survey of forest fragments and tea plantations, we found the presence of 85 species out of a potential 247 forest-associated species in three tea-growing regions of Fujian Province, southern China. Our expectation of lower diversity in tea gardens was not supported by our data, but we documented significant degree of nestedness, proving that the bird community in tea gardens was drawn from the original forest community.

2. Materials and Methods

2.1. Study Sites

The study sites were in Fujian Province, south-eastern China. Fujian is one of the main tea producing regions of the country, with strong historical traditions, and a mountainous landscape with a humid subtropical climate.

The study was performed at three sites within Fujian Province: in the north-western Wuyishan Mountains (N 27°42′, E 117°56′, 231–375 m asl), on the central highlands at Beifeng (N 26° 10′, E 119° 23′, 575 m asl), and in the south-eastern part of the province, at Anxi (N 24° 57′, E 117° 49′, 814 m asl, Figure S1). At Wuyishan, areas under the ownership of the Red Star Company were used for censuses. This estate is located just outside Wuyishan city. Here two organically managed blocks were selected: a younger one, established 5 years ago with regularly planted indigenous native trees, shrubs and herbs, and a 20 years old block where trees were older and planted as windrows separating tea blocks. Both sites had remnant patches of the original forest vegetation. At Beifeng, the chosen location is under the ownership of the Chunlun Ecological Tea Gardens and specialises on producing jasmine tea. This site was also organically managed, and had discontinuous small strips of tea bushes with island-like patches of natural and pine forests as well as natural grasses and bamboo. Cows and goats were grazed among the tea plants to suppress weeds. At Anxi, organically managed tea plantations of the Juyuan Tea Professional Cooperative were studied. This landscape included unmanaged edges of natural grasses and woody vegetation as well as patches of exotic pine forests and fragments of natural forests.

In each of the three locations, we selected two forest fragments, and their neighbouring tea gardens. For further details concerning the research sites, see Imboma et al. [29].

2.2. Bird Assemblage Survey and Analysis

Birds were censused by the standard point count method [30]. Census points were located 200 m from each other, and if found in a forest, located at least 50 m from its edge. At one site in Beifeng we could not find a large enough forest fragment that could accommodate the six census points that fulfilled the above conditions. Here, four forest census points were in one fragment, while points 5 and 6 were located in two smaller fragments bordering the same tea planation on other sides. Censuses were always done in fair weather during the morning hours (06:00–10:30) when bird activity was the highest, and lasted 10 min per census point. On arrival to a point, a 5 min. "acclimatisation period" was held [30]. The sequence of census points was varied randomly. Birds seen or heard were recorded

within a radius of 50 m. Identification was done by using MacKinnon and Phillips [16] and only those species with confirmed identity are reported in this study. Two unknown species of warblers (<5 individuals) were excluded from the analyses. Fixed-radius point counts were used instead of open-radius point counts or transect counts in order to control for differences in detection range among sampling sites with different vegetation structure [31]. A single observer (T.S.I.) undertook all bird counts, which reduced detection bias associated with differences in observer performance.

All sampling dates were classified into seasons: autumn 2018, spring 2019, and summer 2019. Samples taken on 9, 10, 11 August, and 5, 6, 13, 14 September in 2018 were termed "Autumn 2018" even though the first three belong to the late summer period. Spring 2019 census dates were 30, 31 March, 13, 14, 19, 20 April, and summer 2019 included dates of 21, 22, 29 June, and 1, 26, 27, 28 July. There was always equal sampling effort devoted to forest and tea (on the same dates or maximum one day apart) at any site, so these were always directly comparable. The primary analysis considers tea vs. forest as habitats, and the three locations (Anxi, Beifeng, and Wuyishan) were analysed separately, so any eventual difference in sampling effort that might have occurred between locations was irrelevant, and we did not correct for those.

2.3. Data Structure

When repeated censuses are made in the same area, almost inevitably the same species are recorded in various numbers. One cannot be certain which one is the correct number, so it is customary to consider the maximum number recorded within a season as the number closest to reality [14]. The spatial arrangement of the count points in this research ensured spatial independence for most species; therefore, we first established the abundance at a census point, which was taken as the highest number recorded at that point during one season. Subsequently, we calculated the abundance per site as the sum of the numbers observed at the six point counts in one season as the "true" abundance. Exceptions to this were aerial-hunting species including swallows (two species, *Hirundo rustica*, *H. daurica*), the Blue-throated Bee-eater (*Merops viridis*), as well as the following wide-ranging species: Asian Koel (*Eudynamys scolopaceus*), Oriental Cuckoo (*Cuculus saturatus*), Eurasian Jay (*Garrulus glandarius*), Oriental Turtle Dove (*Streptopelia orientalis*), Black-billed (*Pica pica*), and Red-billed Blue Magpie (*Urocissa erythrorhyncha*), Black-collared Starling (*Sturnus nigricollis*), and Crested Myna (*Acridotheres cristatellus*). For these species, the maximum number recorded at one census point in a habitat (forest or tea) at a site during the season was taken as the abundance (no. of individuals observed) at that site. Additionally, the following water-associated species were excluded from the analysis: Cattle Egret (*Bubulcus ibis*), Little Egret (*Egretta garzetta*), Common Kingfisher (*Alcedo atthis*), and White-breasted Waterhen (*Amaurornis phoenicurus*) because water reservoirs were not present at all sites. The initial dataset contained 5776 individual records at the three locations. After filtering the above way, 4924 records were kept for analysis. Due to the absence of data on species conspicuousness, data were considered relative densities, and were not interpreted in terms of true densities as suggested by Fuller and Langslow [32]. Although N-mixture models are technically appropriate to estimate absolute abundance by incorporating probability of detection [33], estimating the actual population size was not the aim of this study. Moreover, N-mixture models do not perform well under low probabilities of detection [34]. Therefore, we tested for differences in species richness and abundance using generalized linear mixed models using the abundance data described as above.

2.4. Potential Species Pool of Forest Birds in Fujian Province

We constructed a potential pool of birds that occur in forests in Fujian, using the list compiled by Lepage [35]. This list contains 552 species recorded in Fujian Province, of which 32 species are globally endangered (vulnerable, endangered, or critically endangered). From this list, we deleted nonforest birds such as seabirds, herons, storks, pelicans, geese, and ducks. Of the remaining species, we consulted MacKinnon and Philips [16] and del Hoyo et al. [36] to check their preferred habitats, and eliminated bird species that do not occur in forests and areas with trees (forest fragments, bushes,

and similar). After this procedure, there were 247 bird species left as potential candidates for our observations. We used this potential pool as the basis for calculating nestedness.

2.5. Statistical Analysis

First, we determined whether the sampling effort was sufficient by generating rarefaction curves for every habitat type and location combination (2 × 3). The effects of habitat, season, and locations on overall bird abundance were tested using a generalised linear mixed model with negative binomial distribution, where census site was considered as a random factor in the experimental design. Model selection was done using the Akaike information criterion (AIC) [37]. To reveal significant difference between multiple levels in a categorical factor, we used the Tukey's post hoc test through the R package *multcomp* [38].

We compared the diversity of bird assemblages using several biodiversity indices: Shannon's diversity index, Simpson's index, Pielou's evenness index, and the Berger–Parker dominance index. We also calculated Rényi diversity profiles [39] for each forest-tea habitat pair as

$$HR(a) = \frac{1}{1-a} \log \sum_{i=1}^{S} p_i^a \tag{1}$$

where $\alpha \geq 0$, $\alpha \neq 1$, p_i is the relative abundance of the *i*-th species, and S is the number of species; α is a so-called scale parameter.

The Rényi diversity belongs to the one-parametric diversity index families [40], and has four special cases:
(i) at $a = 0$, $HR(0) = \log S$, the value is the logarithm of the number of species;
(ii) when $\alpha => 1$, the Rényi diversity is identical with the Shannon diversity;
(iii) at $a = 2$, the value of the Rényi diversity is:

$$HR_2 = \log 1/D \tag{2}$$

where D equals the quadratic or Simpson diversity;
(iv) when the value of the scale parameter is large ($a \rightarrow +\infty$), the Rényi diversity becomes

$$H_\infty = \log 1/d = \log 1/p_{max} \tag{3}$$

where d is the Berger–Parker diversity or index of dominance, and p_{max} is the relative abundance of the most common species.

We explored how much diversity was explained at point census level (α diversity), between point censuses, between sites, locations, and habitat types (β diversity) using the additive partitioning method [41].

Nestedness of the assemblages was tested following Rodrıguez-Gironés and Santamaria [42]. Evaluating whether habitat type or location affected the bird assemblages, we employed the Bray Curtis dissimilarity index.

All calculations were performed using the R software version 3.6.1 [43] through RStudio [44] and using the R package *vegan* [45] and *diverse* [46].

3. Results

3.1. Species Abundance

The best model selected using the AIC included only the effect of season as a fixed factor and census site as a random factor. The overall bird abundance in the forest fragments (mean = 18.4 ind., SD = 9.1) was not significantly different (GLMM, $p = 0.991$) from that on tea plantations (mean=18.1 ind., SD=9.8). Moreover, there were no significant differences (Tukey's post hoc, $p = 0.162$–0.743) between overall

abundances at Anxi (mean = 16.8 ind., SD = 7.8), Beifeng (mean = 19.4 ind., SD = 11.0), and Wuyishan (mean = 18.3 ind., SD = 9.0). However, overall bird abundance was significantly lower during autumn 2018 (mean = 12.7 ind., SD = 7.9) than in spring (mean = 20.0 ind., SD = 9.2) and summer 2019 (mean = 20.2 ind., SD = 9.2) (Tukey's post hoc, $p < 0.001$ for both comparisons). In general, abundances were lower during the autumn than in spring or summer in most sites (Figure 1), although the abundance peak was observed in the spring in Beifeng, and on the tea plantations in Beifeng and Wuyishan (Table 1, Figure 1).
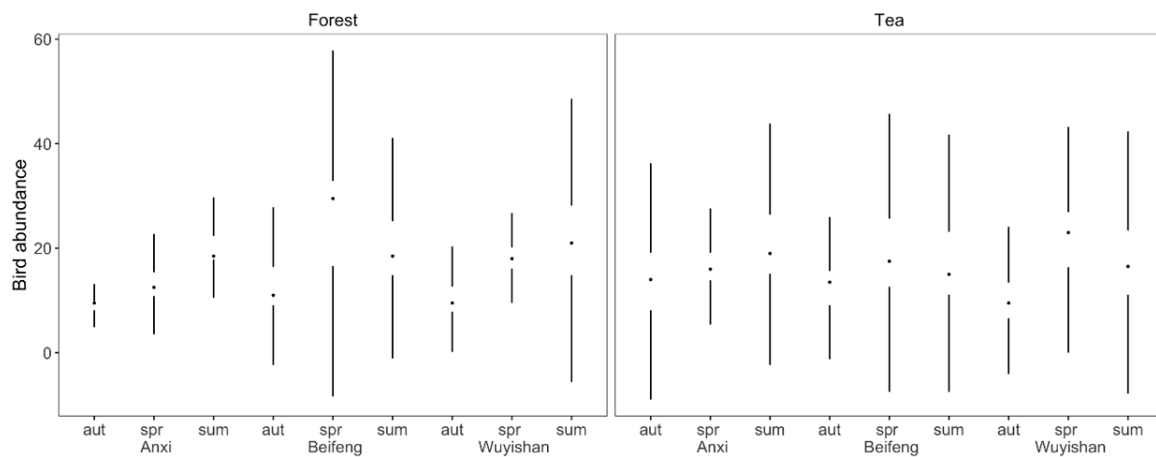
Figure 1. Bird abundance (mean no. of individuals observed/census point) trends in forest patches and tea plantations in three seasons (aut = autumn 2018; spr = spring 2019; sum = summer 2019) at three tea-growing locations of Fujian Province, south-eastern China. The dots indicate medians, the gap marks the central quartiles, and the vertical lines the upper and lower quartiles, respectively.

Table 1. The number of individuals and species observed * at three tea-growing locations in Fujian Province, south-eastern China, 2018–2019.

Location, Habitat	No. Individuals (Species) Observed in			Individuals Season^{-1} ±SD	Species Season^{-1} ±SD
	Autumn 2018	Spring 2019	Summer 2019		
Anxi, forest	112 (17)	169 (26)	243 (24)	14.5 ± 5.0	5.6 ± 0.7
Anxi, tea	180 (19)	194 (24)	497 (28)	24.3 ± 13.2	7.0 ± 3.1
Beifeng, forest	171 (17)	311 (31)	486 (33)	27.0 ± 12.4	6.6 ± 2.9
Beifeng, tea	176 (17)	215 (22)	415 (23)	22.6 ± 9.9	5.6 ± 1.6
Wuyishan, forest	134 (19)	259 (26)	528 (32)	25.7 ± 16.1	6.8 ± 2.9
Wuyishan, tea	124 (17)	265 (25)	445 (39)	23.2 ± 12.5	6.9 ± 2.5

* Data are censored. See Section 2.3 for details on how datasets were generated.

3.2. Species Richness and Composition

Over the three seasons at the three sites, a total of 82 species were identified, with a recorded abundance of 4924 individuals (Table S1). Although this accounted only for 33.2% of the species pool identified from the literature, the species accumulation curves (Figure S2) indicated that the species richness in both habitat types at all locations was sufficiently described. Overall, the 10 most abundant species accounted for 52.4% of the total number of individuals registered. The five common species were the Light-vented Bulbul (557 ind.), the Black-throated Tit (*Aegithalos concinnus*, 417 ind.), the Great Tit (296 ind.), the Masked Laughingthrush (*Garrulax perspicillatus*, 246 ind.), and the Rufuous-capped Babbler (*Stachyris ruficeps*, 195 ind.) (Table S1). These species were present at most of the census sites. However, the Chinese Babax (*Babax lanceolatus*, 157 ind.) and the Crested Myna (109 ind.), although among the abundant species, were present only at Anxi and Beifeng, respectively. Most of the recorded species (59 spp.) were passerines.

3.2.1. Bird Assemblage at Anxi

There were 52 species and 1395 individuals recorded, with 42 species (524 ind.) in the forest and 39 (871 ind.) on the tea plantations. The most common species were the Chinese Babax, Light-vented Bulbul, Rufous-capped Babbler, White-browed Laughingthrush, and Huamei (*G. canorus*). These were the most abundant species on the tea plantations, too. In the forest, the five most abundant were the Rufous-capped Babbler, Light-vented Bulbul, Streak-breasted Scimitar Babbler (*Pomatorhinus ruficollis*), Huamei, and the Grey-cheeked Fulvetta (*Alcippe morrisonia*).

3.2.2. Bird Assemblage at Beifeng

At Beifeng, there were 1774 individuals of 51 species recorded, 47 species (968 ind.) in the forest and 32 species (806 ind.) in the tea plantations. The most abundant species included the Light-vented Bulbul, Black-throated Tit, Great Tit, Crested Myna, and the Collared Finchbill (*Spizixos semitorques*). In the tea, more Barn Swallows and White-browed Laughingthrushes were observed than Finchbills, while the most abundant species in the forest was the Black-throated tit, and the top five included the Greater Necklaced Laughingthrush (*Pterorhinus pectoralis*) instead of the Crested Myna.

3.2.3. Bird Assemblage at Wuyishan

At this site, 51 species (1755 ind.) were included in the list, with 41 species (921 ind.) in the forest and 47 species (834 ind.) in the tea plantations. The list of the most abundant species showed close similarity to Beifeng: it included the Light-vented Bulbul, Black-throated Tit, Great Tit, Masked Laughingthrush, and Collared Finchbill. On the tea plantations, there were more Huamei than Finchbill, and in the forest, more Huamei than Laughingthrush (Table S1).

3.3. Community Composition

3.3.1. Patterns of Commonness and Rarity

Among the abundant species, only the Light-vented Bulbul was recorded at all locations, habitats, and seasons. The Great Tit and Huamei also showed nearly-universal occurrence (17 of the possible 18 records), while six other passerine species (Masked and White-browed Laughingthrushes (*G. sannio*), Rufous-capped (*Stachyris rufipes*) and Streak-breasted Scimitar Babblers (*Pomatorhinus ruficollis*), Yellow-bellied Prinia (*Prinia flaviventris*), and Scaly-breasted Munia (*Lonchura punctulata*) were also frequently recorded (>13 of the possible census location/habitat/season combinations).

Considering species of which at least five individuals were seen, only the Grey-capped Greenfinch (*Carduelis sinica*) proved to be a "tea specialist"—no individual of this species was recorded in the forest. No individuals of six species were seen in tea plantations at all: Greater Necklaced Laughingthrush, Ashy Minivet (*Pericrocotus divaricatus*), Common Tailorbird (*Orthotomus sutorius*), Rufous-faced warbler (*Abroscopus albogularis*), Water pipit (*Anthus spinoletta*), and Orange-flanked bush robin (*Tarsiger cyanurus*). These can be considered "tea avoiders".

There were six species recorded as singletons: the Eurasian (*Accipiter nisus*) and the Chinese Sparrowhawk (*A. soloensis*), Pied Harrier (*Circus melanoleucos*), Oriental Cuckoo, Silver Pheasant (*Lophura nycthemera*), and the Eurasian Collared Dove (*Streptopelia decaocto*). At Anxi, an additional singleton was the Barred Buttonquail (*T. suscitator*), at Beifeng, the Scarlet Minivet (*Pericrocotus flammeus*), and at Wuyishan, the Asian Koel. All these can be considered accidental occurrences. Four species were recorded as doubletons, and all of them at one place, one season: the Japanese Sparrowhawk (*A. gularis*), Mountain Bamboo Partridge (*Bambusicola fytchi*), Yellow-legged Buttonquail (*Turnix tanki*), and the White-bellied Erpornis (*Erpornis zantholeuca*). The almost overlapping rank-abundance curves suggest that evenness was similar in each habitat type and location (Figure 2).
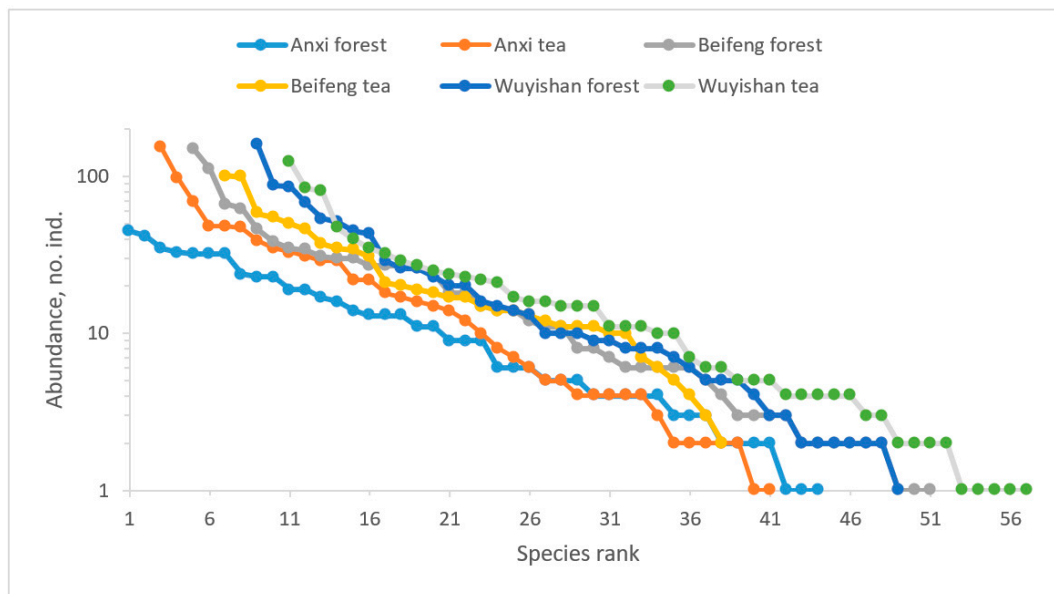
Figure 2. Rank-abundance curves of the bird assemblages recorded at six sites in forest fragments and tea plantations at three locations in Fujian Province, China. The vertical axis is logarithmic scale. The individual curves are staggered for better visibility.

3.3.2. Diversity

One-Parameter Diversity Indices

The diversity of bird assemblages did not show great seasonal variation (Table 2) and were without statistically significant differences. In general, the forest sites had a higher diversity than the respective tea plantation sites, although occasionally the opposite was found and the Wuyishan tea plantation sites had a surprisingly high diversity (Table 2). Simpson's diversity was high (mostly >0.9) with a minimum of 0.87 at the tea plantation at Anxi and the forest in Beifeng, both in autumn 2018 (Table 2). Pielou's evenness index was higher in the forest at Anxi, but not at the other two locations, and was generally high. The Berger-Parker dominance index had relatively low values (0.15–0.21), indicating low dominance by the most common species. The bird assemblage at the Wuyishan tea plantations was among the most diverse locations, irrespective of the statistic used (Table 2).

Table 2. Diversity indices of bird assemblages living in three tea-growing locations in Fujian Province, south-eastern China, 2018–2019.

| Diversity Index/Season	Anxi		Beifeng		Wuyishan	
	Forest	Tea	Forest	Tea	Forest	Tea
Shannon index						
Autumn 2018	2.57	2.35	2.32	2.44	2.66	2.54
Spring 2019	2.96	2.75	2.96	2.88	2.68	2.68
Summer 2019	2.93	2.94	3.06	2.77	3.01	3.2
Mean ± SD	2.82 ± 0.22	2.68 ± 0.30	2.78 ± 0.40	2.69 ± 0.23	2.78 ± 0.20	2.81 ± 0.35
Simpson index						
Autumn 2018	0.92	0.87	0.87	0.89	0.92	0.91
Spring 2019	0.94	0.92	0.92	0.94	0.89	0.91
Summer 2019	0.94	0.93	0.94	0.93	0.94	0.95
Mean ± SD	0.93 ± 0.01	0.91 ± 0.03	0.91 ± 0.04	0.92 ± 0.03	0.92 ± 0.03	0.92 ± 0.02
Pielou's evenness						
Autumn 2018	0.91	0.8	0.82	0.86	0.9	0.9
Spring 2019	0.91	0.86	0.86	0.93	0.82	0.83
Summer 2019	0.92	0.88	0.87	0.88	0.87	0.87
Mean ± SD	0.91 ± 0.01	0.85 ± 0.04	0.85 ± 0.03	0.89 ± 0.04	0.86 ± 0.04	0.87 ± 0.04
Berger–Parker dominance index						
Autumn 2018	0.18	0.23	0.25	0.23	0.17	0.19
Spring 2019	0.14	0.17	0.23	0.11	0.29	0.17
Summer 2019	0.13	0.16	0.16	0.13	0.12	0.12
Mean ± SD	0.15 ± 0.03	0.19 ± 0.04	0.21 ± 0.05	0.16 ± 0.06	0.19 ± 0.09	0.16 ± 0.04

Patterns of Diversity

Of the total (γ) diversity, 16.39% was due to the α diversity (within point census), 20.19% between point censuses, 11.02% between sites, 35.19% between locations, and 17.22% between habitat types. There were no significant differences between habitat types for any of the diversity indices (Table 2). The forest assemblages were the most species-rich in Beifeng, while little different from each other at the other two locations, Wuyishan and Anxi. However, the diversity relationships started to change almost immediately, once the assemblage structure was considered: the assemblage at Anxi became the most diverse, and remained so as the scale parameter increased. The bird assemblages at Beifeng were unequivocally more diverse than the one at Wuyishan (Figure 3). The assemblage observed on the tea plantations was most species-rich at Wuyishan, and remained unequivocally more diverse than the one at Anxi. The assemblage at Beifeng was not so species-rich nor contained so many rare species, but was less dominated by common species, as at around $\alpha = 2$, it crossed the curve of Wuyishan, and remained above it (Figure 4). At Anxi, the bird assemblage of the forest was unequivocally more diverse than the one of the tea plantation, while the opposite was observed at Wuyishan. At Beifeng, the bird community of the forest was more diverse than that of the tea plantation in terms of species richness and rare species, but became less diverse at $\alpha > 2$ (Figures 3 and 4).
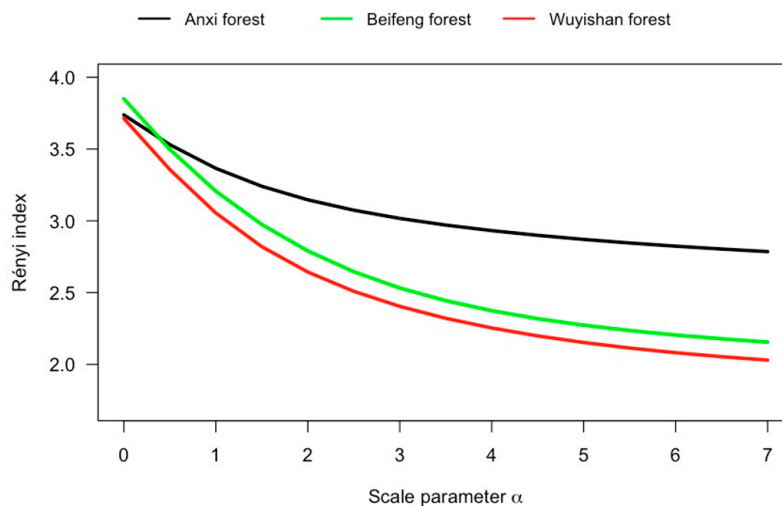

Figure 3. The Rényi diversity profiles of bird assemblages observed in forest fragments at three tea-growing locations in Fujian Province, south-eastern China.
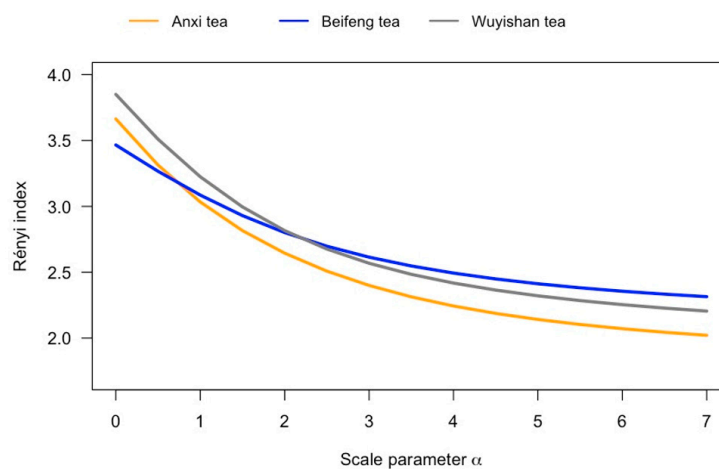
Figure 4. The Rényi diversity profiles of bird assemblages observed on tea plantations at three tea-growing locations in Fujian Province, south-eastern China.

The rarefaction curves (Figure 5) showed that the forest assemblages were more diverse than those observed on the nearby tea plantations at both Anxi and Beifeng: the species richness was higher (higher maxima) as well as the evenness (steeper increase of the rarefaction curve). The situation was the reverse at Wuyishan, where more species occurred on the tea plantations and the assemblage also displayed a higher evenness (Figure 5).
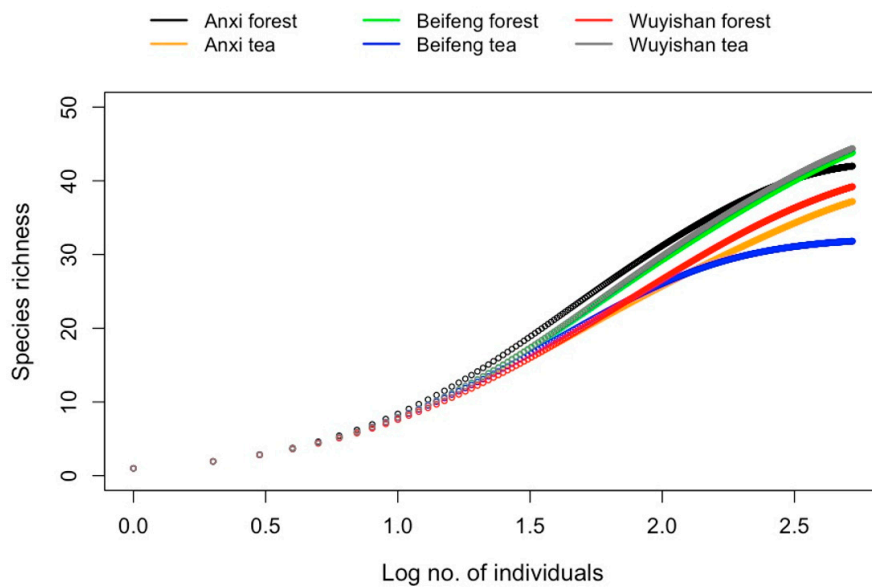

Figure 5. Rarefaction curves of species richness of bird assemblages in forests and tea plantations at three tea-growing locations in Fujian Province, south-eastern China.

Nestedness of Bird Assemblages

The bird assemblages were significantly nested (C score = 169.29, $p < 0.001$, Figure 6) with nestedness temperature of 18.86 and 28.6% matrix fill, indicating that most species of the species pool were not recorded in our studied sites, and that most of the observed species were present in all respective subsets. When the registered total list of species was considered the source, the nestedness became even more significant, with a nestedness temperature of 33.95 and a matrix fill of 50.62%. Assemblages were more similar within the same location than similar habitat types were to each other (Figure 7), which suggested no biotic homogenisation across locations.
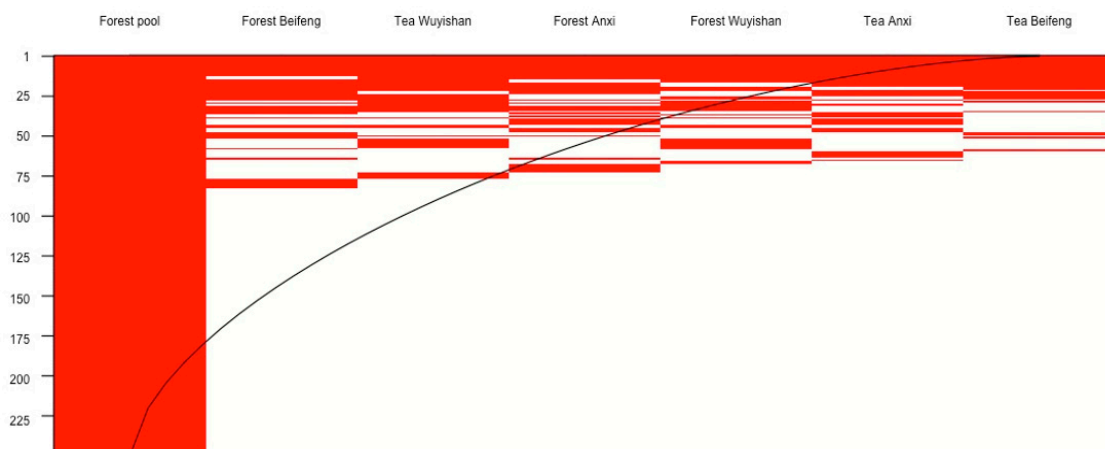
Figure 6. Nestedness of the bird assemblages in forest patches and tea plantations in three locations of Fujian Province, China, with respect to the forest species pool, drawn from Lepage [35].
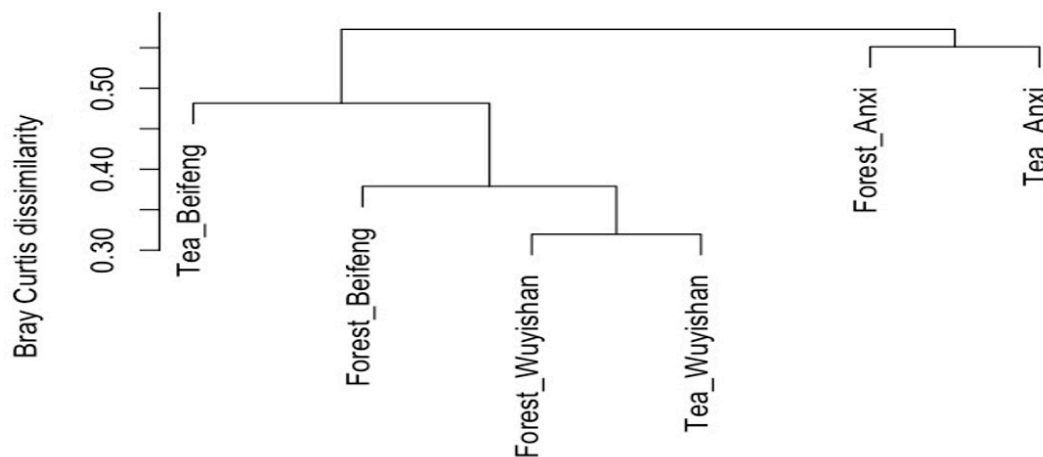
Figure 7. Bray–Curtis dissimilarity of the six bird communities recorded in forest fragments and on tea plantations at three tea-growing locations of Fujian Province, south-eastern China.

4. Discussion

Our study documented the occurrence of 82 species at three tea-growing locations in Fujian Province. These were overwhelmingly local residents, with only the occasional presence of migrants (possibly the Blue-throated Bee-eater, *Merops viridis*) none of which showed high abundance. The presence of winter residents cannot be excluded but our censuses did not cover the winter period. During the field observations, two species were observed that were new to the province. These were the Chestnut Bulbul (*Hemixos castanonotus*), a common canopy species in Wuyishan, Anxi, and Beifeng; and the Grey-Cheeked Fulvetta (*Alcippe morrisona*) a forest species found at all locations, and even on tea plantations at Wuyishan. The overall species richness compares favourably with the few examples of avifaunal surveys on tea plantations in other areas of China. In Yunnan, Yang et al. [47] found 43 species, and surveys in Anhui Province report 14–31 species [22,48]. An extensive survey in a protected forest area at similar geographical latitude in the Nanling Mountains, Guanzhou Province, reported 80 species [18], and a year-long survey found 51 species in Dinghushan Nature Reserve, in the neighbouring Guangdong Province [49]. Unfortunately, a more quantitative comparison is not possible, because most of the pre-existing literature contains occurrence lists and descriptive notes only. However, there are 247 potential forest species in Fujian [16,35], indicating that tea-growing landscapes across Wuyishan, Anxi, and Beifeng retained ca. 30% of the potential forest avifauna. Analysing diversity we included several of the one parameter diversity indices even though for comparative purposes only. The Renyi-diversity approach is clearly simpler and more suitable for a synthetical understanding of diversity trend changes. This method, combined with the nestedness approach could be useful for analysing other, similar fragmented habitats that harbour endangered species.

Not surprisingly, the biggest loss is of forest specialists. Only a fraction of species inhabiting continuous forest can survive in this modified landscape. Typically, birds observed on tea plantations were also recorded in the forest fragments—the only "tea specialist" was the Grey-capped Greenfinch. There were several species, though, that were only observed in the forest.

Birds provide important biocontrol function by consuming arthropod pests in cultivated land [50]. Common species in Anhui tea plantations include the Great Tit (*Parus major*), Barn Swallow (*Hirundo rustica*), the Light-vented Bulbul (*Pycnonotus sinensis*), Vinous-throated Parrotbill (*Paradoxornis webbianus*), the Japanese White-eye (*Zosterops japonicus*), and the Forest Wagtail (*Dendronanthus indicus*) [24]. These are considered important natural enemies of tea pests, and we found several of the above species or close relatives also in our surveys. In northern India, four bird species, the Asian-pied Starling (*Gracupica contra*), Chestnut-tailed Starling (*Sturnia malabarica*), Jungle Myna (*Acridotheres fuscus*), and the Red-vented Bulbul (*Pycnonotus cafer*) are identified as potentially

effective biocontrol agents against pest caterpillars [25]. In the studied landscape, we found that birds regularly moved out of the forest fragment, and a concurrent study [29] found an attack rate of 19–25% d^{-1} on sentinel prey placed on tea plants. The rate of attack increased as the distance to the next forest fragment edge increased. It is safe to conclude that these birds were not accidentally visiting tea plantations. At the same time, the role of the forest fragments is important, and as the case of Wuyishan tea gardens proves, planting trees, especially native trees can encourage birds into tea plantations.

Shaded tea cultivations with diverse shade trees and the adjacent forest fragments and remnant patches have a much higher capacity for enriched biodiversity within the matrix [27,28] than tea monocultures [51]. Such intercropped shade trees provide enriched habitat and feeding grounds that support forest specialists as well forest generalists [25]. Compared to Anxi and Beifeng, the tea plantations in Wuishan, the young plantation in particular was systematically structured with more plant species, including trees, shrubs, and herbs, some of which were flowering providing an increased habitat heterogeneity and additional resources in a human modified landscape. The older tea plantations were structured with hedgerows and local seminatural habitats. These two environmentally friendly landscape management options provided for a much higher avian diversity in Wuyishan.

Considering tea gardens as a habitat which, though cultivated, is under a mild disturbance regime and of long duration, we suggest it is worth investing in landscape management, analysing the network of forest fragments as sources for biocontrol agents, as well as conservation tools. This approach can increase bird diversity above those of individual forest fragments [52], and could result in more effective biocontrol which, in turn, can lessen dependence on pesticides [53] that are problematic in tea anyway. Such planned biodiversity, beyond an improved quality and increased quantity of tea production, can accommodate additional ecosystem services including pollination, nutrient cycling, and regulation of the local microclimate [53].

Active landscape management, with a view of developing methods of management of forest patches as a habitat network rather than mere abandonment, taking into account such determinants as patch size, composition, and forest fragment network structure is worth consideration, because dispersal limitation may be at work in fragmented forests [54]. This could bring a double benefit: maintaining habitat for forest-inhabiting birds, while benefiting from their presence due to their biocontrol function. Providing nesting opportunities for hole-nesting species can further increase the conservation value of these cultivated habitats. Further research should be directed to examine the relationship between bird diversity, abundance, and ecosystem service provision in comparison to similar characteristics and functions by invertebrates.

5. Conclusions

In this first survey of birds visiting tea gardens and nearby forest patches, we identified 82 bird species, ca. 30% of the documented forest avifauna in Fujian, many of which regularly visit and spend time in tea plantations, often looking for food. Additionally, we documented the continued presence of 79 forest-associated bird species in fragments of the original forest. Two of these birds were first recorded for Fujian. These findings underline the importance of the remaining forest fragments as refuges for forest-associated birds, and also suggest that these birds may provide pest control services as well as other biodiversity-related benefits. Future work towards developing methods of managing forest patches in a landscape context rather than mere abandonment of inaccessible sites is worthy of consideration, both for bird protection as well as maximising biocontrol benefits obtainable from invertivorous birds.

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