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Photo: Avery Young

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Avian use of avocado farms and intact forest in the northern Sierra de Bahoruco, Dominican Republic

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Cover Page: Young and mature rows of avocado trees near the town of Puerto Escondido, Independéncia, Dominican Republic. This farm, and others in the area, sit in the foothills of the Northern Sierra de Bahoruco that can be seen in the distance. Many endemic and Neotropical migrant bird species inhabit these mountains including the tropical dry forest communities in the foothills where avocado farming is an increasing concern. Photograph by Avery Young in October 2021.

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Abstract
The Dominican Republic is experiencing increased forest loss due to the expansion of avocado farming. While agricultural lands can provide viable habitat for birds, knowledge of avian use of avocado farms relative to native forest is limited. We conducted surveys in fall 2021 to compare the bird communities and vegetation complexity of two avocado farm sites and two native dry forest sites in the northern Sierra de Bahoruco region of the Dominican Republic to assess avian habitat use. Overall, we found that habitat associations differed for bird species distinguished by contrasting geographic ranges. In particular, the abundance, richness, and diversity of bird species endemic to Hispaniola were significantly greater in forests than in farms, while non-endemic resident bird species had the opposite habitat associations. The abundance, richness, and diversity of Neotropical migrants exhibited fewer distinct differences between farm and forest sites. Vegetation structural complexity was reduced in avocado farms relative to forests and was positively associated with the abundance, richness, and diversity of endemic bird species but negatively associated with these community measures of non-endemic resident species. Collectively, our findings suggest that avocado farms could provide viable habitat for non-endemic resident and migrant bird species, but that endemic species could be negatively impacted by an increase in avocado farming in the region. We offer recommendations for forest preservation, farming practices, and future research that could help to inform the conservation of endemic species in the region.

Keywords
agriculture, avian conservation, Dominican Republic, endemic species, habitat use, land-use change, Neotropical migrants

Resumen
Uso de granjas de cultivo de aguacate y bosques nativos por parte de las aves en el norte de la Sierra de Bahoruco, República Dominica • La República Dominicana está experimentando una mayor pérdida de bosques nativos como consecuencia de la expansión de los cultivos de aguacate. Aunque las tierras agrícolas pueden proporcionar un hábitat propicio para algunas aves, el conocimiento sobre el uso que hacen de los cultivos de aguacate en comparación con las áreas forestales nativas es limitado. En otoño de 2021, realizamos muestreos en dos granjas de aguacate y dos bosques secos nativos en la región norte de la Sierra de Bahoruco (República Dominicana), y comparamos las comunidades de aves y la complejidad de la vegetación para evaluar el uso del hábitat que hacen las aves. En general, observamos diferencias entre las asociaciones de hábitats de las especies de aves con distribuciones geográficas distintas. En particular, la abundancia, riqueza y diversidad de especies de aves endémicas de La Española fueron significativamente mayores en los bosques que en las granjas; mientras que las especies de aves residentes no endémicas mostraron asociaciones de hábitat opuestas. La abundancia, riqueza y diversidad de las aves migratorias neotropicales exhibieron menos diferencias entre las granjas y los bosques. La complejidad estructural de la vegetación se redujo en las granjas de aguacate en relación con los bosques y tuvo una correlación positiva con la abundancia, riqueza y diversidad de aves endémicas, pero negativa con las mismas medidas comunitarias de especies residentes no endémicas. En conjunto, nuestros resultados sugieren que los cultivos de aguacate podrían proporcionar un hábitat adecuado para aves residentes no endémicas y migratorias; mientras que las especies endémicas podrían verse afectadas negativamente por un aumento de

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estos cultivos en la región. Por último, proporcionamos recomendaciones para la conservación de los bosques, prácticas agrícolas y futuras investigaciones que podrían contribuir a la conservación de las aves endémicas de esta región.

Palabras clave
agricultura, aves migratorias neotropicales, cambio de uso de suelo, conservación de aves, especies endémicas, República Dominicana, uso de hábitat

Résumé
Utilisation par les oiseaux des plantations d'avocatiers et des forêts non exploitées dans le nord de la Sierra de Bahoruco, en République dominicaine • En République dominicaine, la forêt indigène est en régression en raison de l'augmentation de la culture des avocatiers. Bien que les terres agricoles puissent fournir un habitat approprié à certains oiseaux, les connaissances sur l'utilisation des plantations d'avocatiers par rapport à celle des forêts indigènes sont limitées. Nous avons échantillonné deux plantations d'avocatiers et deux forêts sèches indigènes dans la Sierra de Bahoruco (République dominicaine) au cours de l'automne 2021, et nous avons comparé leurs communautés d'oiseaux et la complexité de leur végétation afin d'évaluer l'utilisation de ces deux habitats par les oiseaux. Dans l'ensemble, nous avons observé que les associations entre espèces d'oiseaux et habitats différaient en fonction de la répartition géographique des oiseaux. En particulier, l'abondance, la richesse et la diversité de l'avifaune endémique à Hispaniola étaient significativement plus fortes dans les forêts que dans les plantations, tandis que les espèces d'oiseaux sédentaires non endémiques étaient inversement associées à ces habitats. L'abondance, la richesse et la diversité des migrateurs néotropicaux présentaient moins de différences distinctes entre les milieux agricoles et forestiers. La complexité de la structure de la végétation était plus faible dans les plantations d'avocatiers que dans les forêts, et était positivement corrélée à l'abondance, à la richesse et à la diversité des espèces d'oiseaux endémiques, mais négativement corrélée à ces mesures pour les communautés d'espèces sédentaires non endémiques. Dans l'ensemble, nos résultats semblent indiquer que les plantations d'avocatiers pourraient constituer un habitat viable pour les espèces d'oiseaux sédentaires et migrateurs non endémiques, mais que les espèces endémiques pourraient être affectées négativement par une augmentation de ces cultures dans la région. Nous formulons des recommandations pour la préservation des forêts, les pratiques agricoles et les recherches futures qui pourraient contribuer à la conservation des espèces endémiques dans la région.

Mots clés
agriculture, changement d'affectation des terres, conservation de l'avifaune, espèces endémiques, migrateurs néotropicaux, République dominicaine, utilisation des habitats

Rapid environmental change is threatening biodiversity worldwide, and birds are the vertebrate taxa with the greatest number of species on the brink of extinction (Ceballos *et al.* 2020). Owing to their high bird species diversity and high rates of habitat loss, the tropics are now home to the highest number of bird species threatened by extinction (Sodhi *et al.* 2011, BirdLife International 2017). In addition to affecting year-round resident bird species, land-use change in the Neotropics can affect Nearctic-Neotropical migrants that stop over or overwinter in these habitats. A recent assessment of the status of North America's avifauna concluded that a net loss of 3 billion birds has occurred during the last 50 years, among 419 migratory species (Rosenberg *et al.* 2019). Declines in bird populations have been linked directly to habitat encroachment from the conversion of land for agriculture and development (BirdLife International 2017, Tilman *et al.* 2017). More than 50% of the world's tropical forests have already been modified by human use (Laurance *et al.* 2014), and bird species in highly biodiverse tropical systems have been especially negatively affected by industrial agriculture practices and other human activities (Newbold *et al.* 2013). However, differences in farming practices, such as crop intensity and organic farming methods do impact biodiversity loss (Tuck *et al.* 2014).

The island of Hispaniola, comprised of the Dominican Republic and Haiti, is used by more bird species than any other island in the Caribbean, with the exception of Cuba (Gerbracht and Levesque 2019). Hispaniola provides both important overwintering and stopover habitats for Neotropical migrants (Wunderle and Latta 1998, Latta and Brown 1999, Latta *et al.* 2003) and permanent habitat for resident bird species (Latta *et al.* 2006). Forest-dependent breeding birds in tropical ecosystems, including endemic species, are considered to be the most vulnerable to habitat disturbance (Newbold *et al.* 2013), and Hispaniola harbors more endemic bird species than any other island in the Caribbean except for Jamaica (Latta *et al.* 2003). In particular, the Sierra de Bahoruco region in the southwestern Dominican Republic is home to 30 endemic bird species (Latta 2005, Latta *et al.* 2006), including nine species listed as vulnerable to extinction or endangered (IUCN 2022). Deforestation associated with land conversion for agriculture is an ongoing concern for avian biodiversity in the Dominican Republic, including in the Sierra de Bahoruco (Latta 2005). Over half of the country's deforestation is a direct result of agriculture growth, including illegal farming within national protected areas in Sierra de Bahoruco (León *et al.* 2013, Lloyd and León 2019). In total, the Dominican Republic experienced a loss of ~300,000 ha of tree cover from 2000–2019, with the majority of forest loss attributed to land conversion for agriculture (Global Forest Watch 2021).

Classic ecological studies have revealed a generally positive association between bird species diversity and vegetation structural complexity (MacArthur and MacArthur 1961), a factor that is generally greater in forests than most agricultural systems (Flynn *et al.* 2009, Karp *et al.* 2012). Although it has been proposed that bird and plant species diversity also should be correlated, empirical support for this association has been mixed (e.g., MacArthur and MacArthur 1961, Power 1972, Nilsson 1979, Erdelen 1984, Estades 1997, Rompré *et al.* 2007, Mohd-Azlan *et al.* 2019). While avian species diversity is generally greater in tropical forests than agricultural lands (MacGregor-Fors and Schondube 2011), certain species may more successfully use converted agricultural landscapes based on their ecological and life-history traits (Newbold *et al.* 2013, Regos *et al.* 2018), such as diet, body size, and foraging height (Bain *et al.* 2020). Migrant species in particular may be better adapted to use modified landscapes than resident species because of generally more flexible requirements on non-breeding grounds (Hutto 1980, Villaseñor and Hutto 1995, Bender *et al.* 1998, Newbold *et al.* 2013). Given that endemic species are characterized by smaller ranges and stricter habitat requirements (Rabinowitz 1981, Cronk 1997, Fordham and Brook 2010), endemic bird species are often more vulnerable to human disturbance and landscape modification than geographically widespread bird species (Harris *et al.* 2014, Martin *et al.* 2020).

Understanding associations between avian diversity and land cover can provide important conservation guidance for the Sierra de Bahoruco region and other tropical forest areas of the Caribbean experiencing deforestation for agriculture. To date, many studies of bird use of agricultural lands in the tropics have focused on coffee and cacao plantations (e.g., Wunderle and Waide 1993, Perfecto *et al.* 1996, Wunderle and Latta 1996, Greenberg *et al.* 1997a, 1997b, Johnson 2001, Tejeda-Cruz and Sutherland 2004, Johnson *et al.* 2006, Van Bael *et al.* 2007, MacGregor-Fors *et al.* 2018). Such research in the Dominican Republic and elsewhere has shown that shade-grown coffee plantations with significant overstory canopy are more extensively used as foraging habitat for resident and migrant birds compared with full-sun coffee plantations that lack overstory canopy (Wunderle and Waide 1993, Perfecto *et al.* 1996, Greenberg *et al.* 1997a, Wunderle and Latta 1998, Tejeda-Cruz and Sutherland 2004). This habitat preference of birds could be explained by the similarity of shade-grown coffee plantations to more structurally complex forest (Arendt *et al.* 2020) or the amount of native trees in shade coffee plantations relative to other agricultural lands (Narango *et al.* 2019). But studies also have concluded that even shade-grown coffee may not be suitable habitat for highly forest-dependent bird species (Greenberg *et al.* 1997b) or species sensitive to disturbance (Tejeda-Cruz and Sutherland 2004).

Avocados (*Persea americana*) are the most rapidly expanding tropical fruit export worldwide, and global production of avocados has been projected to triple from 2010 to 2030 (OECD-FAO 2021). Given a recent increase in avocado production in the Dominican Republic, the country is now the world's second-largest exporter of avocados (FAOSTAT 2021). The mid-elevation foothills of the Sierra de Bahoruco region have been identified as ideal sites to grow avocados, and native forest in the area has been increasingly converted for avocado farming as a result (León *et al.* 2013). There has been more documentation of forest loss from illegal and legal avocado farming on the southern slope of the Sierra de Bahoruco, with an estimated 3,400 ha of forest loss from agricultural practices including avocado and coffee farming (León *et al.* 2013). The impacts of avocado farming on the northern slope has not yet been studied in similar detail, but avocado agriculture threatens these native dry forests as well (León *et al.* 2013) with an estimated 260 ha of avocado farms in the Puerto Escondido area (Y.M. León pers. comm.). Similar to other tree plantations such as coffee and cacao, avocado plantations can comprise or be integrated within a more complex vegetation structure than non-tree crop farms and could provide viable habitat for bird species (Mokria *et al.* 2022). However, the use of avocado farms by birds, including migrant, non-endemic resident, and endemic species, has not been previously reported in the primary literature.

To investigate avian use of avocado farms in the Dominican Republic's northern Sierra de Bahoruco region, we compared bird species richness and diversity in avocado farms and native dry forest. We considered overall, migrant, and endemic bird species in our analysis, and concurrently assessed the vegetation complexity of farms and forest to better understand factors affecting the diversity and abundance of bird species. We predicted that farms would be characterized by lower vegetation complexity and that this reduced complexity would be associated with lower bird species diversity. Given their habitat associations, we categorized bird species as forest-dependent or generalist and made associated recommendations for land-use and conservation priorities.

Methods

Study Sites

The study area is located near the town of Puerto Escondido, Independéncia Province, in the foothills of the northern Sierra de Bahoruco in the southwestern Dominican Republic. Natural forests in this area are considered subtropical dry forests (Knudson *et al.* 1988) with elevations ranging from 421 to 522 m. Dominant vegetation in the region includes large trees such as baitoa (*Phyllostylon brasiliensis*), candelón (*Acacia scleroxyla*), and guayacán (*Guaiacum officinale*) and understory shrubs such as escobón (*Eugenia monticola*) and grenadilla (*E. ligustrina*). The town of Puerto Escondido is situated near multiple limestone water outlets, providing water for community needs and agricultural irrigation.

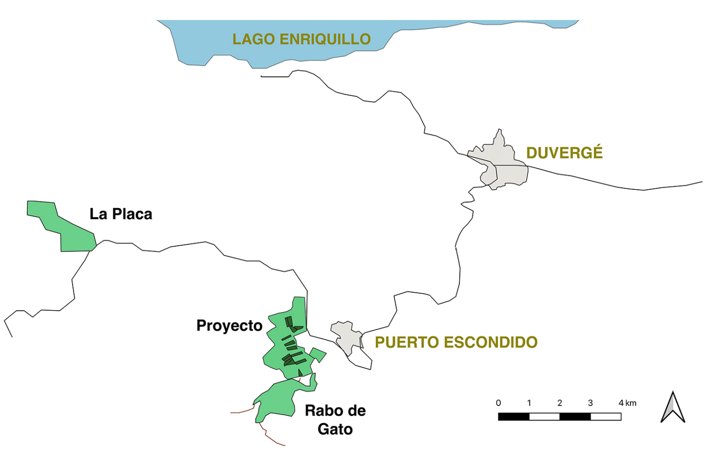

Fig. 1. Map depicting the location of our small farm and La Placa and Rabo de Gato forest study sites (all in green) within the Sierra de Bahoruco region of the Dominican Republic. Dark plots within the small farm area represent active avocado farms. Our large farm study site is not depicted due to a privacy agreement with the landowner.

Table 1. Details of the study sites in the northern Sierra de Bahoruco region of the Dominican Republic in which bird communities and vegetation complexity were assessed in October–December 2021. Due to landowner restrictions, we are unable to provide location information for the large farm site.

	Municipality, Province	Coordinates	Elevation (m)	Area (ha)	Survey points (*n*)
Forests					
La Placa	Reserve Loma de Charco Azul, Independéncia	18°35'50.36"N, 71°65'66.01"W	522	173	29
Rabo de Gato	Puerto Escondido, Independéncia	18°30'80.08"N, 71°59'23.04"W	464	137	24
Avocado Farms					
Large Farm	---	---	442	273	29
Small Farms	Puerto Escondido, Independéncia	18°32'26.94"N, 71°58'99.36"W	421	41	20

We conducted field work in four study sites within the area: two native forest sites and two avocado farm sites. Our first forest site was located in Reserva Loma Charco Azul, a federally protected 17,400-ha dry forest reserve (Fig. 1), known for being the main habitat of the endemic Bay-breasted Cuckoo (*Coccyzus rufigularis*). The second forest site was located adjacent to a portion of a well-known birding trail called Rabo de Gato (Fig. 1). Avocado farms of two sizes were chosen for the comparison to reflect the variety of such farms in the region, including potential differences in vegetation complexity. Specifically, we chose one farm site comprised of multiple, relatively small community parcelas; this is land near town that is divided into adjacent plots, each with a single owner who primarily cultivates one crop. All parcelas cultivating avocados were included in the small farm study site, which was located within 1 km of our forest site at Rabo de Gato (Fig. 1). The second farm site was located in a large organic commercial farm characterized by groves of primarily Hass and Carla avocados. Due to restricted permissions by the landowner, we are unable to disclose the specific location of our large farm site. Both avocado farm sites border native forest, which minimized potential differences in climate, topography, and human disturbance as a result of proximity to town.

Bird Community Surveys

We used point count surveys (Wunderle and Waide 1993, Wunderle and Latta 1996, Greenberg *et al.* 1997a, Marsden *et al.* 2001, Latta *et al.* 2003, Kennedy *et al.* 2010) to assess overall, endemic, and migrant bird communities in the study sites. We designated survey points using a grid system in which all points were at least 150 m apart to reduce the possibility of double-counting individual birds. We also ensured that all points were > 25 m away from the boundary of the site so that only species within the site were detected during surveying. The size and elevation of our study sites and the number of survey points in each site are listed in Table 1.

We conducted point count surveys from 13 October to 1 December 2021 to include resident overwintering migrant species. We visited each point three times during the field season, and alternated between forest and farm point counts on consecutive days to account for differences due to the effects of weather or other short-term temporal events. We began surveys at sunrise and ended no later than four hours after sunrise, encompassing the period when birds are most active and likely to be detected. We recorded all birds seen or heard within 25 m of each point for a 10-min period. Using a relatively small point count radius ensured that we were recording bird species within the habitat type we were surveying, which was especially critical in smaller avocado farms. Birds that flushed upon arrival were included in the point count, but birds flying over without stopping in the site were not counted. We averaged the number of individual birds and species across the three survey dates at each point. To investigate habitat use by non-endemic resident, endemic, and Neotropical migrant species, in particular, we similarly calculated the mean number of individuals and bird species within each group per survey point. Endemic bird species were defined as those only found in Hispaniola and its satellite islands (Latta *et al.* 2006), and migrant bird species were defined as those that breed north of the Tropic of Capricorn but winter south of this location (Hagan and Johnston 1992). Migrants may be passing through to locations further south or overwintering at our site, but by mid-October almost all migrants that are present are winter residents (Wunderle and Latta 1996). We used the term 'non-endemic resident' to describe more geographically widespread, non-migratory species observed in our study sites.

To characterize the diversity of the non-endemic resident, endemic, and migrant bird communities in each study site, we calculated the frequency of each species identified as the percentage of the total bird survey points in each site in which that species was observed across all three site visits. We used the Shannon Diversity Index (Shannon 1948) to calculate the diversity of the overall, non-endemic resident, migrant, and endemic bird communities in each site during each visit. We averaged the diversity scores of the three visits to calculate a mean diversity measure per point. Bird survey details, including the distance that birds were identified from survey points, method of detection, weather variables, and ambient noise are provided in our Dryad dataset (Young *et al.* 2023).

Vegetation Complexity Measures

We assessed canopy cover, canopy height, and canopy thickness at each bird survey point and at four additional subpoints, one in each cardinal direction 25 m from the main survey point (see Van Bael *et al.* 2007). Canopy cover was estimated by using a tube densiometer at each survey point and subpoint. To determine canopy height and canopy thickness, we used a digital rangefinder to measure height of the highest and lowest foliage associated with trees at each survey point and subpoint. Canopy thickness was calculated as the upper height minus the lower height at each measurement location (see Muth and Bazzaz 2002, Mas and Dietsch 2004, Lee *et al.* 2020). We averaged the vegetation data collected at each survey point and its subpoints to calculate the mean canopy cover, canopy height, and canopy thickness for each survey point.

To assess the diversity of vegetation in each study site, we defined the five most dominant woody species ≥ 1 m tall as the species with the highest vegetative cover by visually estimating percent cover in a 25-m radius around each bird survey point (see McLaren *et al.* 2019). For cultivated crops, we included horticultural varieties as 'species' in our analyses given that horticultural varieties are selected for distinct differences in traits that could potentially impact habitat preference, including leaf shape and size and fruiting phenology. To characterize the diversity of the vegetation in each study site, we calculated the frequency of each dominant plant species as the percentage of the total survey circles in each site in which that species was observed across all three site visits. Vegetation survey details are provided in our Dryad dataset (Young *et al.* 2023).

Statistical Analyses

We tested for the normality of our data distribution within groups (i.e., sites) with the Shapiro-Wilk test and for homogeneity of variances among groups with Levene's test. When the assumptions of normality and homogeneity of variances were both met, we used a one-way ANOVA to test for the effect of site on vegetation complexity (i.e., canopy height, canopy cover, canopy thickness) and bird community measures (i.e., number of individuals, species richness, species diversity) followed by least-significant difference LSD post-hoc tests when the effect was significant. When the assumption of normality was met but variances were not homogenous, we used Welch's ANOVA followed by Games-Howell post-hoc tests when the effect was significant. When the assumption of normality was not met but variances were homogenous, we used non-parametric Kruskal-Wallis tests to test for the main effect of site followed by Dunn-Bonferroni post-hoc tests when the effect was significant. In all cases, differences in mean values were considered significant if $p \leq 0.05$. To examine associations between vegetation complexity and bird community measures, we performed linear regression analyses. To account for the numerous associations analyzed, we calculated and utilized corrected *p*-values to control the false discovery rate for the group of tests for each bird community type (i.e., non-endemic resident, endemic, migrant) in accordance with methods described by Benjamini and Hochberg (1995). Results of regression analyses were considered significant if False Discovery Rate (FDR)-corrected $p \leq 0.05$. All data analyses were conducted with SPSS (version 29, IBM Corp., Armonk, NY, USA).

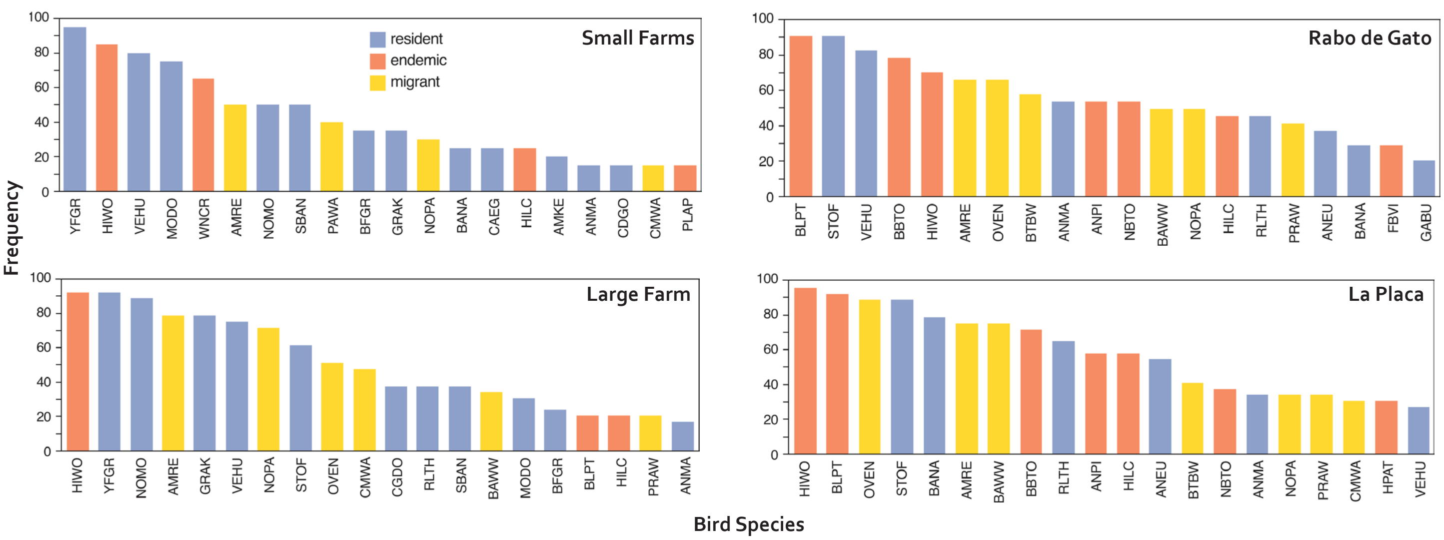

Fig. 2. Frequency of the 20 most commonly observed bird species at each study site expressed as the percentage of total survey points at which each species was observed. Study sites included small and large avocado farms and native dry tropical forest at La Placa and Rabo de Gato. Bird species were categorized as non-endemic residents, endemics, or Neotropical migrants as described in our methods. Abbreviations, English common names, and scientific names for each species are provided in Appendix 1.

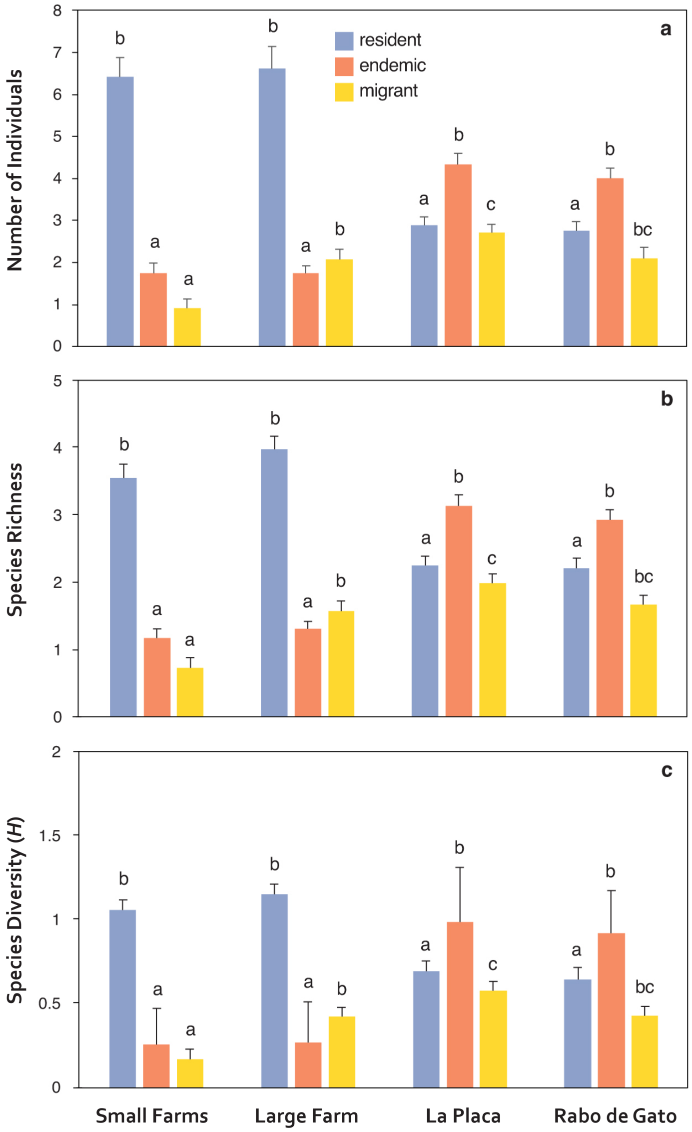

Fig. 3. Abundance of individuals (a), species richness (b), and species diversity (c) of non-endemic residents, endemic, and Neotropical migrant bird species in small and large avocado farm sites and native dry tropical forest sites at La Placa and Rabo de Gato. Values shown are means averaged across multiple survey points in each site ±1 SE of the mean. Within species groups (i.e., non-endemic residents, endemics, migrants), values shown below the same lowercase letter do not differ at the $p \leq 0.05$ level of significance.

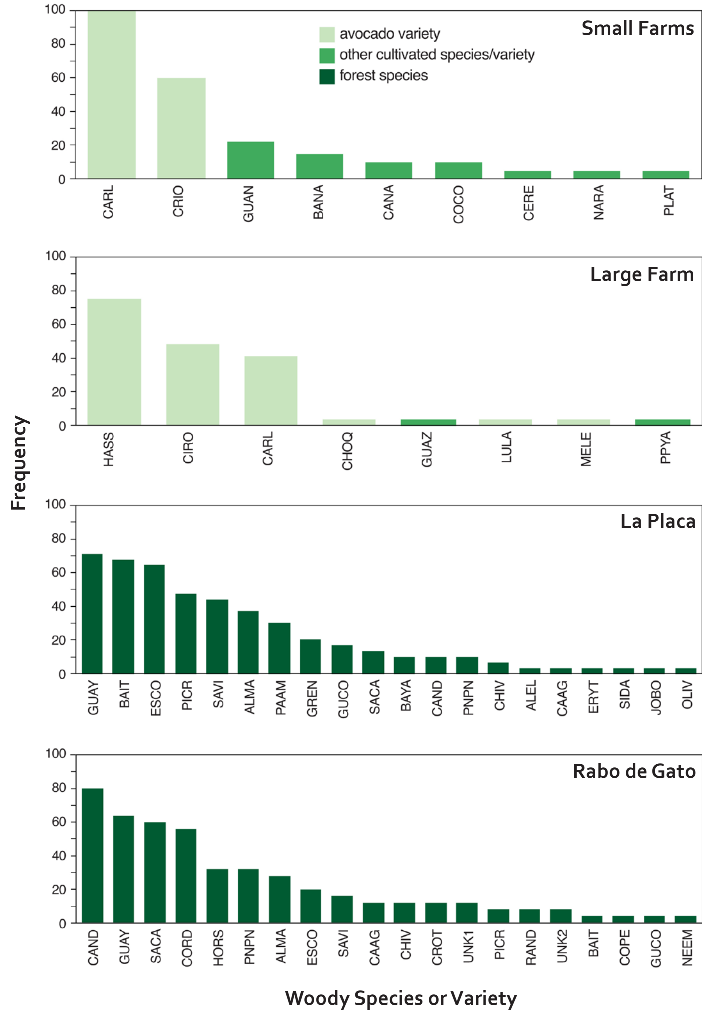

Fig. 4. Frequency of the 20 most commonly observed woody plant species or varieties at each study site expressed as the percentage of total survey points at which each species was observed. Study sites included small and large avocado farms and native dry tropical forest at La Placa and Rabo de Gato. Abbreviations, local common names, and scientific names for each species are provided in Appendix 2.

Results

Bird Community Comparisons

The number of bird species detected across all survey points was similar in all of our study sites (38 species in the big farm, La Placa, and Rabo de Gato; 36 species in the small farm), but the relative abundance of bird species in the forest sites exhibited more evenness than in the farm sites (Fig. 2; see Appendix 1 for bird species abbreviations and scientific names). Of the 20 most frequently observed bird species at each site, the farm sites were characterized by greater numbers of non-endemic resident species than the forest sites, while the forest sites were characterized by greater numbers of endemic bird species than the farm sites (Fig. 2). Detection frequencies of migrants were similar in the big farm and forest sites, but migrants were less frequently detected in the small farm site (Fig. 2).

The mean number of non-endemic resident bird individuals observed per survey point was significantly greater in both farm sites than in both forest sites (Welch's ANOVA: $F_{3,49.096} = 30.14$, $p \leq 0.001$; Fig. 3a). Compared with the forest sites, the farm sites also were characterized by greater non-endemic resident species richness ($F_{3,98} = 27.69$, $p \leq 0.001$; Fig. 3b) and diversity ($H_3 = 38.14$, $p \leq 0.001$; Fig. 3c). Endemic bird communities exhibited opposite trends. Specifically, both farm sites were characterized by significantly lower numbers of endemic individuals ($F_{3,98} = 36.67$, $p \leq 0.001$; Fig. 3a), endemic species richness (Welch's ANOVA: $F_{3,51.963} = 52.21$, $p \leq 0.001$; Fig. 3b), and endemic species diversity ($H_3 = 64.87$, $p \leq 0.001$; Fig. 3c) than both forest sites. The mean abundance of migrant birds observed per

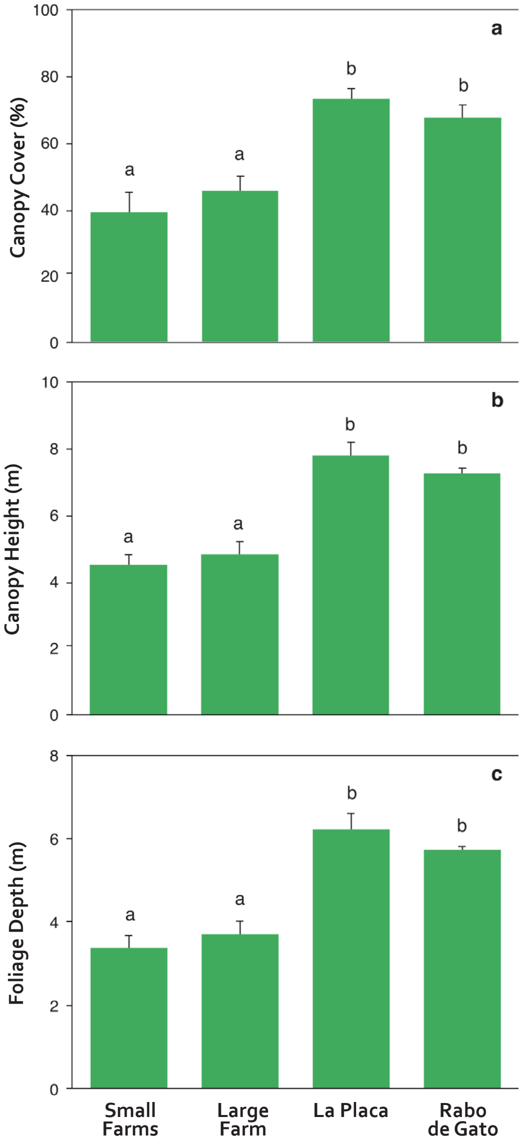

Fig. 5. Canopy cover (a), canopy height (b), and canopy thickness (c) in small and large avocado farms sites and native dry tropical forest sites at La Placa and Rabo de Gato. Values shown are means averaged across multiple survey points in each site ±1 SE of the mean. Values shown below the same lowercase letter do not differ at the $p \leq 0.05$ level of significance.

sampling point was lower in the small farm than in all of the other sites, while the mean number of migrant individuals in the big farm was less than in La Placa but not Rabo de Gato ($H_3 = 25.89$, $p \leq 0.001$; Fig. 3a). The small farm also was characterized by less migrant species richness and diversity than all of the other sites, while the big farm had lower richness and diversity of migrant species than La Placa only ($F_{3,98} = 11.61$, $p \leq 0.001$ for migrant species richness; $F_{3,98} = 7.972$, $p \leq 0.001$ for migrant species diversity; Figs. 3b, c).

Vegetation Complexity Comparisons

More woody plant species or varieties comprised the dominant vegetation in the forest sites (25 species in La Placa, 21 species in Rabo de Gato) than in the farm sites (8 species or varieties in the big farm, 9 species or varieties in the small farm), and the relative abundance of woody species in the forest sites exhibited more evenness than in the farm sites (Fig. 4; see Appendix 2 for plant species and variety abbreviations and scientific names). The five most dominant woody species observed in farm sites comprised ~95% of the total woody species observed in those sites (Fig. 4). In contrast, the five most dominant woody plant species observed in forest sites comprised ~35% of the total woody species observed in those sites (Fig. 4). As expected, woody vegetation in the farm sites was largely comprised of avocado varieties (Fig. 4), which collectively comprised ≥ 90% of the total trees surveyed in each farm. Both farm sites were characterized by less vegetation structural complexity assessed as mean canopy cover ($H_3 = 33.53$, $p \leq 0.001$; Fig. 5a), canopy height (Welch's ANOVA: $F_{3,45.469} = 41.27$, $p \leq 0.001$; Fig. 5b), and canopy thickness (Welch's ANOVA: $F_{3,48.926} = 35.24$, $p \leq 0.001$; Fig. 5c) than both forest sites.

Relationships of Vegetation Complexity and Bird Communities

The number of individuals and the richness and diversity of endemic bird species were positively correlated with all measures of vegetation structural complexity (Table 2). In contrast, the mean abundance and species richness and diversity of non-resident endemic species and Neotropical migrants were not significantly correlated with any measures of vegetation complexity (Table 2).

Discussion

Avian Use of Forests versus Farms

Our comparison of bird communities in two avocado farm sites and two forest sites in the northern Sierra de Bahoruco, Dominican Republic, suggests that the increase in avocado farms could affect bird communities in the region but that the impacts may differ among types of birds and types of farms. Overall, we found that avocado farms could provide suitable habitat for non-endemic resident, endemic, and Neotropical migratory bird species as we observed numerous individuals from multiple species of all of these groups in all of the study sites. However, further study on species and species assemblage health metrics over time would be needed to determine the true viability of this habitat. We also found that avocado farms were frequented by fewer endemic species but more non-endemic resident bird species than forests (Fig. 2), suggesting that forest habitats are preferred by endemic species.

Our observation of reduced abundances and diversity of endemic bird species in both farm sites (Fig. 3) also suggests that native forest habitat is especially important to endemic bird species in the northern Sierra de Bahoruco region. Many endemic species that we observed, such as both the Broad-billed Tody (*Todus subulatus*) and Narrow-billed Tody (*T. angustirostris*), were found almost exclusively in the forests. Distinctions in vegetation complexity between farms and forest (Figs. 4, 5) and associations between vegetation complexity and endemic bird communities (Table 2) suggest that the presence of a dense canopy is important to endemic species. Given their narrow geographical ranges, endemic species are more likely to be dependent on specific habitats (Harris and Pimm 2004). For example,

Table 2. Results of linear regression analyses of associations between measures of vegetation complexity as predictors and non-endemic resident, endemic, and Neotropical migrant bird communities as response variables. Regression that are significant have p-values ≤ 0.05. Negative slopes indicate negative correlations between the predictor and response variable, and vice versa.

Predictor	Response Variable	Slope	R^2	*P*-value
Canopy Cover	*Non-endemic Residents*			
	Number of Individuals	−0.124	0.936	0.0990
	Species Richness	−0.050	0.853	0.0760
	Species Diversity	−0.014	0.865	0.0788
	Endemics			
	Number of Individuals	0.084	0.972	0.0158
	Species Richness	0.062	0.985	0.0103
	Species Diversity	0.024	0.972	0.0140
	Neotropical Migrants			
	Number of Individuals	0.038	0.693	0.7515
	Species Richness	0.027	0.716	0.7515
	Species Diversity	0.008	0.691	0.5070
Canopy Height	*Non-endemic Residents*			
	Number of Individuals	−1.258	0.963	0.1710
	Species Richness	−0.516	0.904	0.0821
	Species Diversity	−0.147	0.909	0.1058
	Endemics			
	Number of Individuals	0.841	0.992	0.0120
	Species Richness	0.625	0.997	0.0180
	Species Diversity	0.239	0.992	0.0090
	Neotropical Migrants			
	Number of Individuals	0.355	0.617	0.2408
	Species Richness	0.258	0.638	0.3618
	Species Diversity	0.079	0.615	0.2160
Canopy Thickness	*Non-endemic Residents*			
	Number of Individuals	−1.463	0.956	0.0990
	Species Richness	−0.598	0.892	0.0707
	Species Diversity	−0.171	0.893	0.0795
	Endemics			
	Number of Individuals	0.979	0.989	0.0108
	Species Richness	0.728	0.994	0.0135
	Species Diversity	0.278	0.988	0.0090
	Neotropical Migrants			
	Number of Individuals	0.421	0.637	0.3030
	Species Richness	0.306	0.657	0.4253
	Species Diversity	0.094	0.635	0.2610

the Bay-breasted Cuckoo, which we observed only in La Placa, inhabits exclusively low to mid-elevation forest in the transitional zone between dry and broadleaf forest of Hispaniola (Latta *et al.* 2006). Another endemic species, the Hispaniolan Emerald (*Riccordia swainsonii*), relies on high elevation moist habitat where it makes nests from wet forest mosses and lichen (Latta *et al.* 2006). We suggest that many endemic species in the Sierra de Bahoruco may be less able to adapt to or utilize human-modified landscapes, such as avocado farms, relative to overwintering migrants and non-endemic resident birds.

In contrast, the greater frequency, abundance, richness, and diversity of non-endemic resident bird species in our avocado farm sites compared with the forest sites (Figs. 2, 3) suggests an ability to adapt or adjust to land-use change that reduce vegetation complexity (Figs. 4, 5; Table 2). Birds frequently observed in avocado farms included numerous common resident species in the Caribbean, such as Yellow-faced Grassquit (*Tiaris olivaceus*), Northern Mockingbird (*Mimus polyglottos*), Gray Kingbird (*Tyrannus dominicensis*), and Smooth-billed Ani (*Crotophaga ani*; Latta *et al.* 2006). These species are not usually observed in forests, but are more generally associated with open landscapes, such as grasslands and disturbed habitats (Latta *et al.* 2006). Increased environmental heterogeneity in human-disturbed landscapes, such as farmlands, can lead to higher niche availability (Lack 1969, Tews *et al.* 2004, Stein *et al.* 2014), and may be one reason for the overall high diversity of non-endemic residents in avocado farms. We suggest that the commonness of species associated with such habitats could be facilitated by the high rates of deforestation in the Caribbean in recent decades (López-Carr *et al.* 2022). In contrast, studies have revealed that habitat specialists are less frequent in disturbed landscapes than generalist species (Devictor *et al.* 2008), a pattern that we suggest is reflected by the low frequency of endemic species in avocado farms in our study.

Our surveys beginning in mid-October may have included transient individuals that were only stopping over at our sites, but all species we observed are known to overwinter on the island. Although Neotropical migrant birds were more frequently observed in forest sites compared with small avocado farms (Fig. 2), our results suggest that large farms could support an abundance of migrant individuals and a diverse migrant community comparable to that of some forest habitat (Fig. 3). However, we acknowledge that our research did not include replicate large farm or small farm sites. As such, these results could reflect local-scale patterns that are not related to farm size, and we encourage future replicate studies to help determine the influence of farm size on bird diversity. Migrants have been known to utilize disturbed habitats while they were on non-breeding grounds (Hutto 1980, Villaseñor and Hutto 1995, Bender *et al.* 1998, Newbold *et al.* 2013), but our results suggest that migrant utilization of farms differs across sites and species. For example, the Prairie Warbler (*Setophaga discolor*) was never observed in the small farm site. Similarly, the Ovenbird (*Seiurus aurocapilla*) was seen only once in the small farm site but was observed in more than half of the sampling points in the big farm and both forest sites. Given the similar complexity of vegetation of our small and large farm sites (Figs. 4, 5), differences in their migrant species and communities suggest that other factors could influence migrant habitat choice. These factors could include food availability (Martin and Karr 1986, Johnson and Sherry 2001), broader matrix complexity (Conway *et al.* 1995), or behaviors such as site fidelity (Johnson and Sherry 2001). Previous research on migrant use of forest habitat of varying successional stages in Mexico (Smith *et al.* 2006) and of different habitats in the southern United States (McClure *et al.* 2012) also found that the structural complexity of vegetation did not affect habitat quality for migrant species.

Conservation Implications

The conversion of forests to agriculture associated with avocado production in the Sierra de Bahoruco region, while not necessarily impactful to bird species overall, could have a negative impact on endemic species in Hispaniola, many of which are already vulnerable to extinction (Latta *et al.* 2003, Latta 2005, Isik 2011, León *et al.* 2013). However, although endemic communities were more robust in our forest sites than farm sites, some specific endemic species seemed to be more generalist in their habitat preferences. For example, both Hispaniolan Woodpecker (*Melanerpes striatus*) and Hispaniolan Lizard-Cuckoo (*Coccyzus longirostris*), which are considered common throughout the island (Latta *et al.* 2006), were found frequently in both forest and farm sites. Other endemic species seemed to prefer habitat that is less forested. In particular, the White-necked Crow (*Corvus leucognaphalus*), which has a limited geographical range and is listed as vulnerable to extinction (IUCN 2022), was observed more frequently in the small farm than in any of the other sites. Notably, we did not observe this species in avocado trees, but rather in larger remnant trees in the small farm site. This observation suggests that shade trees within farmlands may improve habitat quality for bird species in agricultural landscapes.

Caribbean islands are hotspots of endemism and should thus be considered as areas of high conservation priority (Latta 2005, Buchanan *et al.* 2011, Devenish-Nelson *et al.* 2019). Hispaniola in particular is home to 31 endemic bird species and 50 endemic subspecies (Latta *et al.* 2006). The IUCN Red List (IUCN 2022) shows that information about habitat requirements and population numbers is deficient or lacking altogether for many bird species endemic to Hispaniola, which limits the ability to make specific conservation recommendations. Many Hispaniolan endemics are forest-dependent specialists, and our findings demonstrate the vulnerability of endemic species to habitat modification involving deforestation (Greenberg *et al.* 1997b). Endemic species including the Green-tailed Warbler (*Microligea palustris*), Narrow-billed Tody, and Flat-billed Vireo (*Vireo nanus*), which are all considered to have decreasing or data-deficient populations (IUCN 2022), were observed only once or not at all in the farm sites, suggesting that these endemic species are forest-dependent and therefore vulnerable to deforestation. The Bay-breasted Cuckoo was only observed at La Placa, suggesting that the distribution of this species may be especially narrow or reliant on specific habitat requirements, such as limited human disturbance and the presence of large dry forest trees for nesting. The Hispaniolan Parrot (*Amazona ventralis*), considered vulnerable to extinction (IUCN 2022), was also found only in La Placa. Additional species of concern such as the Broad-billed Tody and Antillean Piculet (*Nesoctites micromegas*) were all found in higher frequencies in the forest sites than in avocado farms.

When evaluating avian use of agricultural land, it is important to consider differences between farms, as we found for migrant use of the large and small avocado farm sites. Our results suggest that Neotropical migrants may be less influenced by vegetation complexity than non-endemic resident and endemic bird species, but could be influenced by other habitat-selection factors. The small farm site included in our study was characterized by a patchwork of individual parcelas that are used to grow a variety of crops. Arboreal croplands—such as avocado, coffee, and cacao—have been shown to have higher diversity of birds than non-arboreal croplands (Estrada and Coates-Estrada 1997). We suggest that crop type variation between parcelas could have resulted in smaller arboreal crop patches within the small farm site, which could have decreased utilization by migrant species relative to the more continuous arboreal cropland of the large farm site. Our study did not consider arboreal patch sizes within overall farm sites, which may be an important factor to consider in future research of avian use of avocado farm landscapes in the region. We did observe that endemics such as Hispaniolan Oriole (*Icterus dominicensis*) and White-necked Crow, as well as many migrant warblers, were more likely to be found in the larger trees in the small farm site, such as palm trees, mango trees, or non-pruned large local hybrid avocado trees. This same trend was not observed in the big farm site given that there were very few non-cultivated trees in the site. Overall, the differences that we observed in migrant communities in the small and large farm sites suggest that individual agricultural practices could be important to avian use.

As agriculture continues to expand into tropical forest landscapes (FAO 2009), particularly in areas of high conservation value such as endemic hotspots (Scharlemann *et al.* 2004), the question remains how we can best ensure compatibility of agriculture with species conservation. A variety of agricultural practices have been shown to positively impact habitat quality for birds, such as the preservation of native trees (Douglas *et al.* 2013) including relict shade trees (Wunderle and Latta 1996, Carlo *et al.* 2004), retention of native habitat patches within cultivated landscapes (Estrada-Carmona *et al.* 2019), and use of live fences (Harvey *et al.* 2005). Many tropical bird species have been found to move freely between forest and agricultural lands to benefit from seasonal resources (Estrada and Coates-Estrada 1997), which we suggest could be facilitated by close proximity of farms to intact forest. Forests and scattered trees have been demonstrated in other agricultural areas to improve ecological services including soil fertility and the provision of habitat for native species (Bommarco *et al.* 2013, Reed *et al.* 2017, Yang *et al.* 2020). Both of our farm sites were adjacent to native forest, and future research of avian utilization of avocado farms at different distances from intact forest could provide more understanding of bird movement patterns and farmland habitat quality. While 'bird-friendly' avocado farming practices and proximity of farms to intact forest could enhance avian use, we do not know if these practices would help to support forest specialists, such as the many bird species endemic to Hispaniola in the northern Sierra de Bahoruco. Given the strong association of endemic species with forests demonstrated in our study, we suggest that the preservation of native dry forest in federally-protected reserves like Reserva Loma Charco Azul (La Placa) will be essential for the conservation of endemic bird species.

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Appendix 1. Abbreviations for common names and scientific names of bird species that were among the 20 most frequently observed species in each of the study sites.

Species Code	English Common Name	Scientific Name
AMKE	American Kestrel	*Falco sparverius*
AMRE	American Redstart	*Setophaga ruticilla*
ANEU	Antillean Euphonia	*Chlorophonia musica*
ANPI	Antillean Piculet	*Nesoctites micromegas*
BANA	Bananaquit	*Coereba flaveola*
BAWW	Black-and-white Warbler	*Mniotilta varia*
BBTO	Broad-billed Tody	*Todus subulatus*
BFGR	Black-faced Grassquit	*Melanospiza bicolor*
BLPT	Black-crowned Palm-Tanager	*Phaenicophilus palmarum*
BTBW	Black-throated Blue Warbler	*Setophaga caerulescens*
CAEG	Cattle Egret	*Bubulcus ibis*
CGDO	Common Ground Dove	*Columbina passerina*
CMWA	Cape May Warbler	*Setophaga tigrina*
FBVI	Flat-billed Vireo	*Vireo nanus*
GABU	Greater Antillean Bullfinch	*Melopyrrha violacea*
GRAK	Gray Kingbird	*Tyrannus dominicensis*
HILC	Hispaniolan Lizard-Cuckoo	*Coccyzus longirostris*
HIMA	Hispaniolan Mango	*Anthracothorax dominicus*
HIWO	Hispaniolan Woodpecker	*Melanerpes striatus*
HPAT	Hispaniolan Parrot	*Amazona ventralis*
MODO	Mourning Dove	*Zenaida macroura*
NBTO	Narrow-billed Tody	*Todus angustirostris*
NOMO	Northern Mockingbird	*Mimus polyglottos*
NOPA	Northern Parula	*Setophaga americana*
OVEN	Ovenbird	*Seiurus aurocapilla*
PLAP	Plain Pigeon	*Patagioenas inornata*
PRAW	Prairie Warbler	*Setophaga discolor*
RLTH	Red-legged Thrush	*Turdus plumbeus*
SBAN	Smooth-billed Ani	*Crotophaga ani*
STOF	Stolid Flycatcher	*Myiarchus stolidus*
VEHU	Vervain Hummingbird	*Mellisuga minima*
WNCR	White-necked Crow	*Corvus leucognaphalus*
YFGR	Yellow-faced Grassquit	*Tiaris olivaceus*

Appendix 2. Abbreviations for common names and scientific names of woody plant species and varieties that were among the 20 most frequently observed species and varieties in each of the study sites.

Species Code	Local Common Name	Scientific Name
BAYA	Bayahonda	*Neltuma juliflora*
CAAG	Carga Agua	*Senna atomaria*
CANA	Palma Cana	*Sabal spp.*
CAND	Candelón	*Parasenegalia skleroxyla*
CARL	Carla	*Persea americana var. carla*
CERE	Cereza/Acerola	*Malpighia emarginata*
CHIV	Palo de Chivo	*Senna atomaria*
CHOQ	Choquete	*Persea americana var. choquette*
COCO	Palma de Coco	*Cocos nucifera*
COPE	Copey	*Clusia rosea*
CORD	---	*Cordia laevigata*
CRIO	Criollo	*Persea americana spp. (hybrid)*
CROT	---	*Croton spp.*
ERYT	---	*Erythroxylum brevipes*
ESCO	Escobón	*Eugenia monticola*
GREN	Grenadilla	*Eugenia ligustrina*
GUAN	Guandules	*Cajanus cajan*
GUAY	Guayacán	*Guaiacum officinale*
GUAZ	Guacimo	*Guazuma ulmifolia*
GUCO	Guaconejo	*Amyris elemifera*
HASS	Hass	*Persea americana var. hass*
HORS	Horsua	*Coccoloba diversifolia*
JOBO	Jobo	*Spondias mombin*
LULA	Lula	*Persea americana var. lula*
MELE	Melendez	*Persea americana var. melendez*
NARA	Naranja	*Citrus spp.*
NEEM	Neem/Tree of Heaven	*Ailanthus altissima*
OLIV	Olivo	*Morisonia ferruginea*
PAAM	Palo Amargo	*Rauvolfia nitida*
PICR	---	*Picramnia pentandra*
PLAT	Plátano	*Musa spp.*
PNPN	Piñi Piñi/Quina	*Exostema caribaeum*
PPYA	Papaya	*Carica papaya*
RAND	---	*Randia aculeata*
SACA	Sacasya	*Vachellia macracantha*
SAVI	---	*Savia sessiliflora*
SIDA	---	*Sida glabra*
UNK1	---	*Unknown*
UNK2	---	*Unknown*