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Final Technical Report
Study of Dispersing Forest Birds and Migratory Birds in El Salvador's Apaneca Biological Corridor
28 June 2012

UNDP/RA/GEF Biodiversity Conservation in Coffee Project PIMS#3083
USAID/DAI Improved Management and Conservation of Critical Watersheds Project,
Contract No. EPP-I-00-04-00023-00
U.S. Department of State Award #S-LMAQM-08-CA-103

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*Cover photo: The Yellow-throated Euphonia (*Euphonia hirundinacea*) was one of only six forest-specialist birds to be captured in technified (non-certified) coffee plantations during 10,000 net-hours. Photograph Leticia Andino/SalvaNATURA.*

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ABSTRACT

The study examined three questions: (1) Do dispersing forest-specialist bird species select Rainforest Alliance Certified coffee plantations as movement corridors more than other habitats? (2) Do forest-generalist bird species have higher survivorship or higher proportions of breeding individuals in certified coffee than in other habitats? (3) Do wintering migratory birds have higher survivorship, longer site fidelity, or better condition in certified coffee compared to other habitats? To evaluate these questions, data were generated by capturing 5,652 birds in mist nets at 50 sites distributed evenly among five habitat treatments and across 24 months. The sites were located in the Sierra de Apaneca biological corridor, in southwestern El Salvador. For the first question, 50 individuals of forest-specialist birds were considered to be dispersers. They showed similar preference for natural forest control sites, small forest fragments, and certified coffee plantations (13–15 individuals in each treatment, per 10,000 net hours). Technified coffee plantations presented 6 dispersing individuals, not significantly different from other treatments. Open farmland had just two dispersers, significantly fewer than certified coffee or the forest treatments. For the second question, 1178 capture histories of 22 understory, resident bird species were run through Program MARK. Survivorship likelihood as well as detection probabilities were similar across all habitats. Although the counts of breeding individuals were similar across treatments, the proportion of breeding individuals was significantly lower in certified coffee farms than in all other treatments. A possible explanation for this unexpected result may be that certified farms attract more non-breeding birds than other habitats, reducing the proportion of breeding birds. For the third question, 386 capture histories of 11 species of understory migratory birds were run through Program MARK. Survivorship likelihood as well as detection probabilities were significantly lower in technified coffee than in certified coffee or other habitats. Migrants showed similar site fidelity among certified coffee and forest fragment treatments, and significantly lower site fidelity in technified coffee and open areas. When only between-season (across-year) site fidelity was considered, most treatments presented intermediate site fidelity, but forest fragments had significantly higher site fidelity than technified coffee. Condition in certified coffee was similar to technified coffee and significantly lower than condition in forest fragments. With respect to resident forest-specialist or forest-generalist bird species, Rainforest Alliance Certified coffee plantations in El Salvador were not more bird-friendly than randomly selected, non-certified technified coffee plantations. However, migratory birds in certified farms had higher survivorship and site fidelity, but not better condition, when compared to technified coffee farms. On the other hand, part of Rainforest Alliance certification is the long-term protection of small forest fragments on farm properties. Such fragments, even as small as 7 ha, were found to be important for the conservation of forest-specialist bird species, and presented significantly higher site-fidelity and better body condition for migratory birds when compared to technified coffee farms. These results suggest that conservation set-asides (or offsets) are more important for bird conservation than aspects of agronomy.

¿Están las plantaciones de café “Rainforest Alliance Certified” amigables con las aves?

RESUMEN

El estudio evaluó tres preguntas: (1) ¿Las aves residentes que son especialistas de bosques seleccionan cafetales certificados por Rainforest Alliance como corredores para movimiento, más que otros hábitat, cuando se desplazan? (2) ¿Las aves residentes que son generalistas de bosques tienen mayor supervivencia o mayores poblaciones de individuos reproductores en cafetales certificados que en otros hábitat? (3) ¿Las aves migratorias que visitan a cafetales en el invierno tienen mayor supervivencia, fidelidad de sitio o condición en cafetales certificados, comparados a otros hábitat? Para evaluar estas preguntas, se utilizó redes de neblina para capturar 5,652 aves en 50 sitios, con un esfuerzo distribuido igualmente entre cinco hábitats y 24 meses. Los sitios fueron ubicados en el Corredor Biológico de la Sierra de Apaneca, en el suroccidente de El Salvador. Para la primera pregunta, 50 individuos de aves especialistas de bosque fueron reconocidos como dispersadores; estos mostraron preferencias similares para los sitios con bosque natural, fragmentos pequeños de bosques y cafetales certificados (13–15 individuos en cada tratamiento, por 10,000 horas-red cada uno). Los cafetales tecnificados (no-certificados) presentaron 6 individuos capturados durante su movimiento de dispersión, que no representa una diferencia significativa comparado con otros hábitats. Áreas agrícolas abiertas presentaron solo 2 dispersadores, que era significativamente menos que cafetales certificados y bosques. Para la segunda pregunta, 1178 historiales de captura para 22 especies de aves residentes en el sotobosque fueron analizados con el programa MARK. Las probabilidades de supervivencia y también las probabilidades de detección fueron similares en todos los hábitats. Aunque los conteos de individuos en condición reproductora fueron similares en todos los hábitats, la proporción de individuos reproductores fue significativamente más baja en cafetales certificados que en todos los demás hábitat. Una posible explicación para este resultado imprevisto podría ser que las plantaciones certificadas atraigan más aves no-reproductoras que otros hábitats, resultando en una proporción menor de aves reproductoras. Para la tercera pregunta, 386 historiales de captura de 11 especies de aves migratorias en el sotobosque fueron analizados con MARK. Las probabilidades de supervivencia y también las probabilidades de detección fueron significativamente más bajas en los cafetales tecnificados que en los cafetales certificados y los otros hábitats. Las aves migratorias demostraron fidelidad de sitio similar entre los cafetales certificados y los fragmentos de bosque, pero significativamente más bajo en los cafetales tecnificados y las áreas abiertas. Cuando se consideró solamente la fidelidad entre temporadas (de un año a otro), la mayoría de los hábitats presentó fidelidad intermedia, pero los fragmentos de bosque tuvieron la fidelidad significativamente mayor que los cafetales tecnificados. La condición corporal en los cafetales certificados fue similar a los cafetales tecnificados y significativamente más bajo que la condición corporal en los fragmentos de bosque. Con respecto a las aves residentes de bosques, los cafetales certificados por Rainforest Alliance en El Salvador no fueron más amigables para las aves que los cafetales tecnificados, no certificados y seleccionados al azar. Sin embargo, las aves migratorias en los cafetales certificados tenían mayor supervivencia y mayor fidelidad de sitio, aunque no tenían mejor condición corporal, cuando comparados con los cafetales tecnificados. Por otro lado, una parte de la certificación de Rainforest Alliance es la protección a largo plazo de pequeños fragmentos de bosque adentro de las fincas. Tales fragmentos fueron importantes para la conservación de las especies especialistas de bosques y presentaron significativamente mayor fidelidad de sitio y condición corporal de las aves migratorias cuando comparados con los cafetales tecnificados. Estos resultados sugieren que la conservación de los fragmentos de bosques (tanto locales como ex-situ) sea más importante para la conservación de las aves que los aspectos de la agronomía de café.

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1. EXECUTIVE SUMMARY

This study evaluates several key questions that will contribute to the debate about ecosystem services in a biological corridor, and sustainable management practices in coffee farming. I evaluated ecosystem services provided by coffee plantations, such as habitat for avian biodiversity, and contribution to the conservation of genetic diversity through the facilitation of movement corridors. I examined the relative survivorship rates for forest birds within large patches of natural forest, small forest fragments, certified (Rainforest Alliance) coffee plantations, technified coffee plantations, and open farmland. Also, I asked if migratory bird species, visiting for the winter, have higher survivorship and/or site fidelity in any of these habitats. And I asked if dispersing forest birds selected certain habitats more than others within the corridor for movement across it. Since I used mist net capture data to consider these questions, first I evaluated the detectability (capture probability) of the study species, so that data from the different habitat treatments could be compared and contrasted.

In all, 50 field sites were established, including 10 sites within each of five habitat treatments. The experimental treatments are Forest Fragments (7 to 53 ha in size, mean 19 ha), Rainforest Alliance Certified Coffee farms larger than 5 ha in size, open-canopy Technified Coffee farms larger than 5 ha in size, and Open Areas used for pasture or basic grain production. A control treatment in Natural Forest included sites at El Imposible National Park and San Marcelino Natural Protected Area. All sites are within the Sierra de Apaneca mountain range of southwestern El Salvador, the country's prime coffee production area. At each site, 1000 net-hours were carried out to trap and mark birds, with this effort spread across 12 site visits (one every two months for two years, with visits in every calendar month). In all, more than 5,650 birds were captured during 50,000 net-hours.

Each habitat treatment had a unique vegetation profile. Of particular interest were the high levels of tree species diversity throughout the study area. Tree species diversity declined from 114 species per ha in Natural Forest, to 107 species in Forest Fragments, 60 species in Certified Coffee plantations, 35 species in Technified Coffee plantations, to 21 species in Open Areas (farmland). Tree abundance within these habitats declined along a similar trend. These statistics suggest that current certification criteria of 12 tree species per ha are too easily achieved in El Salvador.

I analyzed 1178 capture histories of 22 understory, resident bird species, and 386 capture histories of 11 species of understory migratory birds. The probability that a resident bird would be detected (recaptured) was similar among the five habitat treatments, averaging 3.7%. Detection probabilities for migrants were also similar among most habitat treatments, and averaged 8.6%. Detectability of migrants, however, was significantly lower in Technified Coffee, just 2.4%. Mean survivorship probability between bimonthly capture periods for all understory resident birds ranged from 66.7% in Open Areas to 84.9% in Technified Coffee (grand mean 78.1%). Survivorship of residents in Open Areas was significantly lower than survivorship in Technified Coffee. For migrants, survivorship averaged 77.5%, but was significantly lower in Technified Coffee (35.0%) compared to other treatments (mean 88.2%).

Forest specialist species were virtually restricted to natural forest and forest fragment habitats. Yet a small number were detected in other habitats, apparently dispersing through the landscape. In all, I recognized 50 forest birds (individuals) as non-resident at the site of capture, and therefore considered them putative dispersers. I analyzed habitat preferences for these dispersing birds, and found that Natural Forest, Forest Fragments, and Certified Coffee had similar frequencies of dispersing birds (13–15 individuals each, per 10,000 net hours) whereas Technified Coffee (6 individuals) presented an intermediate number of dispersing forest birds, not significantly different from other habitats. Open Areas had significantly fewer dispersers (2 individuals) than Certified Coffee or the forest treatments. Considering the large numbers of forest specialist birds resident in the Forest Fragments, I conclude that such fragments are of special importance for the conservation of forest birds, and the provision of stepping stones for dispersing forest birds moving across the corridor. It is noteworthy, too, that forest birds dispersing through the coffee plantations were detectable.

I analyzed habitat use by 1,308 individuals of 41 migrant bird species that winter in El Salvador (breeding in North America). Migrants showed a significant preference for the two types of natural forest treatments as well as Certified Coffee. Fewer migrants occupied Technified Coffee or Open Areas. One strictly transient species, the Canada Warbler (*Cardellina canadensis*), appeared to be more abundant in Certified Coffee habitat, which it occupied as stopover sites during its intercontinental migration between North and South America.

Migrants also showed apparently higher levels of site fidelity in Certified Coffee compared to Technified Coffee (11% vs. 3%, P=0.054). In Forest Fragments, 15% of migrants presented site-fidelity. If only between-season recaptures (birds presenting site fidelity across successive non-breeding seasons in different years) are considered, Forest Fragments presented the most evidence of site fidelity, with 11% of individuals recaptured in a posterior non-breeding season, compared to 3% in Certified Coffee, 2% in Natural Forest, and 2% in Open Areas. However, those differences are not statistically significant. The frequency of between-season site fidelity in Forest Fragments was significantly higher than in Technified Coffee (P=0.003), where no migrants were recaptured in a subsequent season.

Similar results were generated by an analysis of migrant bird condition in the different habitats. Condition was calculated as mass divided by wing length, and then standardized by species. Forest Fragment habitat presented significantly higher condition scores for migrants than did Technified Coffee, Certified Coffee, or Natural Forest. Better condition may explain higher site fidelity and higher abundance of migrants in Forest Fragments.

Resident generalist birds were significantly more abundant in both types of coffee habitat as well as Forest Fragments than in Natural Forest or Open Areas. Counts of individuals in breeding condition were similar across all habitats. The proportions of breeding individuals were also similar in most habitats, but were significantly lower in Certified Coffee. This result suggests that Certified Coffee may be attracting larger proportions of non-breeding individuals than other habitats.

In conclusion, I was unable to detect a significant difference between abundance of dispersing forest birds in Certified Coffee and Technified Coffee treatments. Both treatments appeared to be useful in providing movement corridors, and Certified Coffee had significantly more dispersers than the negative control, Open Areas. Forest Fragments, in addition to providing movement corridors, also presented a surprisingly high abundance of resident forest specialist birds. The study generated compelling evidence that Certified Coffee plantations have higher abundance of migratory birds, and higher site fidelity (an indicator of habitat quality), than either Technified Coffee or Open Areas. The study also has documented the importance of Forest Fragments, more than any other habitat, for migratory bird condition and abundance.

Two mechanisms for adjusting certification strategies for coffee plantations are suggested: (1) Create a mechanism to stress the importance of conservation set-asides, such as woodlots or forest fragments, over the agronomy of eco-friendly agriculture. (2) Adjust the criterion for tree species richness in certified farms, such that it recommends “at least 10 native tree species per hectare more than a local baseline typical of highly disturbed areas”.

2. RESUMEN EJECUTIVO

El presente estudio evalúa varias preguntas claves que contribuirán al debate sobre servicios ecosistémicos en un corredor biológico, y las prácticas de manejo sostenibles en plantaciones de café. Evalué los servicios ecosistémicos proveídos por las plantaciones de café, tales como hábitat para la biodiversidad de aves, y la contribución para la conservación de la diversidad genética a través de la prestación de corredores para movimiento. Examiné las tasas relativas de supervivencia para aves de bosque dentro de grandes parches de bosque natural, pequeños fragmentos de bosque, plantaciones de café certificadas (Rainforest Alliance), plantaciones de café tecnificadas y áreas abiertas. Además, me pregunté ¿si especies migratorias de aves, visitantes de invierno, tienen una mayor supervivencia y/o fidelidad de sitio en cualquiera de estos hábitats? Y, pregunté, ¿si aves dispersadoras de bosque seleccionan ciertos hábitats más que otros para el movimiento a través del corredor? En vista que utilicé redes de neblina para considerar estas preguntas, primero evalué la detectabilidad (probabilidad de captura) de las especies en estudio, para que los datos provenientes de los diferentes tratamientos de hábitats pudiesen ser comparados y contrastados.

En resumen, 50 estaciones de campo fueron establecidas, incluyendo 10 sitios dentro de cada uno de los cinco tratamientos de hábitats. Los tratamientos experimentales son fragmentos de bosque (de 7 a 53 ha de extensión, con un promedio de 19 ha), plantaciones de café certificadas Rainforest Alliance de más de 5 ha de extensión, plantaciones abiertas de café tecnificadas de más de 5 ha de extensión, y áreas abiertas usadas para pastizales o producción de granos básicos. Tratamientos control en bosques naturales incluyen sitios en el Parque Nacional El Imposible y Área Natural Protegida San Marcelino. Todos los sitios se encuentran dentro de la cordillera de la Sierra de Apaneca en el suroeste de El Salvador, principal área de producción de café en el país. En cada sitio, se llevaron a cabo 1,000 horas-red para capturar y marcar aves; este esfuerzo fue repartido a través de 12 visitas a cada sitio (una cada dos meses por dos años, con visitas en cada mes calendario). En total, más de 5,650 aves fueron capturadas durante las 50,000 horas-red.

Cada tratamiento de hábitat tenía un perfil de vegetación único. De particular interés fueron los altos niveles de diversidad de especies de árboles en toda el área de estudio. La diversidad de especies de árboles se redujo de 114 especies por ha en bosque natural a 107 especies en fragmentos de bosque, 60 especies en plantaciones de café certificadas, 35 especies en plantaciones de café tecnificadas a 21 especies en áreas abiertas (cultivos agrícolas). La densidad de árboles dentro de estos hábitats declinó a lo largo de una tendencia similar. Estas estadísticas sugieren que los actuales criterios de certificación de 12 especies de árboles por ha son fáciles de lograr en El Salvador.

Analicé 1,178 historiales de captura de 22 especies de aves residentes del sotobosque, y 386 historiales de captura de 11 especies de aves migratorias. La probabilidad que un ave residente fuese detectada (recapturada) fue similar entre los cinco tratamientos de hábitats, con un promedio de 3.7%. La probabilidad de detección para migrantes fue también similar entre la mayoría de los tratamientos, con un promedio de 8.6%. Sin embargo, la detectabilidad de los migrantes en plantaciones de café tecnificadas, fue significativamente menor, con un promedio de solo 2.4%. El promedio de probabilidad de supervivencia entre períodos bimestrales de capturas para todas las aves residentes de sotobosque fue desde 66.7% en áreas abiertas hasta 84.9% en café tecnificado (gran promedio de 78.1%). La supervivencia de residentes en áreas abiertas fue significativamente menor que la supervivencia en café tecnificado. Para migrantes, el promedio de supervivencia fue 77.5%, pero fue significativamente menor en café tecnificado (35.0%) comparado con otros tratamientos (promedio de 88.2%).

Las especies especialistas de bosque se limitaban prácticamente a los bosques naturales y los fragmentos de bosque. Sin embargo, un pequeño número fue detectado en otros hábitats, aparentemente dispersándose a través del paisaje. En total, reconocí 50 aves de bosque (individuos) como no residentes en los sitios de captura, y por lo tanto, considerados como dispersadores putativos. Analicé preferencia de hábitat para estas aves dispersadoras, y encontré que el bosque natural, fragmentos de bosque y café certificado tienen frecuencias similares de aves dispersándose (13–15 individuos cada por 10,000 horas-red en cada hábitat), mientras el café tecnificado (6 individuos) presentó un numero intermedio de aves de bosque dispersándose, pero no significamente diferente a otros hábitats. Las áreas abiertas tuvieron un número significativamente menor de dispersadores (2 individuos) comparado con el café certificado o los tratamientos de bosque. Considerando el gran número de aves especialistas de bosque residentes en los fragmentos de bosque, concluí que dichos fragmentos son de importancia especial para la conservación de aves de bosque, ya que facilitan refugios o áreas de descanso para aves que se encuentran dispersándose a través del corredor. También es notable la detección de aves de bosque dispersándose a través de plantaciones de café.

Analicé el uso de hábitat de 1,308 individuos de 41 especies de aves migratorias que inviernan en El Salvador (reproducen en Norte América). Las migratorias mostraron una preferencia significativa por los dos tipos de tratamientos de bosque natural, así como también café certificado. Pocos migrantes ocuparon bosque tecnificado o áreas abiertas. Una especie estrictamente transitoria, *Cardellina canadensis*, apareció más abundante en hábitat de café certificado, ocupándolo como sitio de parada durante su migración intercontinental entre el Norte y Sur América.

Las aves migratorias también mostraron aparentemente altos niveles de fidelidad de sitio en café certificado comparado con café tecnificado (11% vs. 3%, P=0.054). En fragmentos de bosque, 15% de migrantes presentaron fidelidad de sitio. Si sólo son consideradas las recapturas entre temporadas (aves que presentan fidelidad de sitio a través de sucesivas temporadas no reproductoras en diferentes años), los fragmentos de bosque presentaron la mayor evidencia de fidelidad de sitio, con un 11% de individuos recapturados en una temporada posterior, comparado con 3% en café certificado, 2% en bosque natural, y 2% en áreas abiertas. Sin embargo, estas diferencias, no son estadísticamente significativas. La frecuencia de fidelidad de sitio entre temporada en fragmentos de bosque fue significativamente mayor que el café tecnificado (P=0.003), donde ningún ave migratoria fue recapturada en una temporada subsecuente.

Resultados similares fueron generados por un análisis de la condición corporal de aves migratorias en los diferentes hábitats. La condición fue calculada como la masa dividida por longitud de ala, y luego estandarizada por especie. Los fragmentos de bosque presentaron niveles de condición significativamente mayores para los migrantes comparado con el café tecnificado, café certificado o bosques naturales. Una mejor condición puede explicar la alta fidelidad de sitio y mayor abundancia de migrantes en los fragmentos de bosque.

Las aves residentes generalistas fueron significativamente más abundantes en ambos tipos de hábitat de café así como en fragmentos de bosque que en bosques naturales o áreas abiertas. Conteos de individuos en condición reproductora fueron similares en todos los hábitats. La proporción de individuos reproductores también fue similar en la mayoría de los hábitats, pero fue significativamente menor en café certificado. Estos resultados sugieren que el café certificado puede estar atrayendo grandes proporciones de individuos no reproductores, en comparación con otros hábitats.

En conclusión, no fui capaz de detectar diferencias significativas entre abundancia de aves de bosque dispersadoras en los tratamientos de café certificado y café tecnificado. Ambos tratamientos parecen ser útiles en proveer corredores para el movimiento, y el café certificado tuvo significativamente más dispersadores que el control negativo, áreas abiertas. Los fragmentos de bosque, en adición de proveer corredores para el movimiento, también presentaron sorpresivamente una mayor abundancia de aves residentes especialistas de bosque. El estudio ha generado evidencia convincente que las plantaciones de café certificado tienen una mayor abundancia de aves migratorias, y mayor fidelidad de sitio (un indicador de calidad de hábitat), que el café tecnificado o áreas abiertas. Este estudio también ha documentado la importancia de los fragmentos de bosque, más que cualquier otro hábitat, para mantener la condición corporal de aves migratorias.

Dos mecanismos para ajustar las estrategias de certificación para plantaciones de café son sugeridas: (1) crear mecanismos para destacar la importancia de apartar terrenos para la conservación, tales como arboladas o fragmentos de bosque, sobre la agronomía de agricultura ecológica. (2) Ajustar el criterio para la riqueza de especies arbóreas en fincas certificadas, de tal manera que se recomienda "por lo menos 10 especies nativas de árboles más por hectárea que una línea base típica de áreas altamente perturbadas".

3. Introduction

Ecological certification programs of cultivated coffee (*Coffea arabica*, Rubiaceae) were created in the 1990s due to concerns about declines of North America migratory birds (Perfecto et al. 1996, Komar 2006b). Certification programs have often been justified in part for their benefits to birds, and some programs explicitly state that they are "bird-friendly". They have also been justified as valid efforts to improve the functionality of biological corridors (Harvey et al. 2008). One of the largest certification programs is promoted by Rainforest Alliance and its partners in the Sustainable Agriculture Network throughout Latin America (and recently in Africa and Asia as well). This program and others have not been rigorously evaluated to quantify their benefits either for birds or for biological corridors. In particular, the relative condition or survivorship of conservation-interest bird species, such as threatened species or forest specialist species, has not been documented in coffee plantations (Komar 2006b). More generally, studies on use of agricultural habitats by wildlife are needed to enable effective planning of biological corridors and stepping stones for wildlife gene flow in human-modified landscapes (Chazdon et al. 2009).

The Apaneca Biological Corridor includes about 1250 km^2 of humid montane forests and shaded coffee plantations on the slopes of the Sierra de Apaneca mountain range, which stretches for some 70 km east to west in southwestern El Salvador. Only about 8% of the corridor are protected natural habitats, and these are distributed in widely separated areas each <4000 ha in size. Most of the land is used to produce coffee under varying densities of shade trees. As with most areas in the Neotropics, the actual functionality of the corridor has not been studied, but it is widely assumed that some species of forest birds or other wildlife maintain gene flow or physical connectivity among the few remaining natural forests, because of the existence of extensive shaded, permanent agriculture in the landscape matrix. Documentation of actual gene flow or dispersal is scant (Komar 2007). The corridor area has been the subject of extensive promotion of sustainable agriculture techniques, through various development projects (Giovannucci et al. 2000, Global Environment Facility 2006, Romanoff 2010) and the establishment of the Apaneca-Ilamatepec Biosphere Reserve in 2007. The Rainforest Alliance Certified program has recently certified more than 10% of the coffee acreage (SalvaNATURA, unpublished data). All of these efforts have assumed that shaded coffee plantations are beneficial to the conservation of birds and other biodiversity (Perfecto et al. 1996).

The Apaneca corridor may really represent two separate corridors for forest bird species. The forest bird communities above 1600 msnm include several highland species not found at lower elevations, such as the Wine-throated Hummingbird (*Atthis ellioti*), Rufous-browed Wren (*Troglodytes rufociliatus*), and the Rufous-collared Robin (*Turdus rufitorques*), all restricted-range species found only in the humid montane forest ecoregion of northern Central America. These species have isolated populations in the Sierra de Apaneca, and are found mostly above the upper limit of coffee cultivation (generally 1600 m) and up to the highest areas of the sierra, at the peak of the Santa Ana (or Ilamatepec) Volcano, at 2365 msnm. For these species, the mountaintop forests and Mexican cypress (*Cupressus lusitanica*) plantations probably form a movement corridor, some 30 km long but just a few km wide. Of more interest to the present study are the forest fragments and coffee plantations on the sierra's lower slopes, between 400 and 1600 msnm, the area that was deforested and converted mostly to coffee plantations during the last 200 years. This area is approximately 70 km long, and 20 km wide on both slopes of the mountain range. Among the regionally-endemic, conservation important species that could be using the corridor are forest generalists such as Rufous Sabrewing (*Campylopterus rufus*), Bushy-crested Jay (*Cyanocorax melanocyaneus*), and Bar-winged Oriole (*Icterus maculialatus*). Also potentially using this lower corridor are forest specialist species that are mostly restricted to the large patches of protected forests, such as Northern Bentbill

(*Oncostoma cinereigulare*), Long-tailed Manakin (*Chiroxiphia linearis*), and Blue Bunting (*Cyanocompsa parellina*).

Few previous studies have addressed issues related to bird conservation in tropical biological corridors. Most have focused only on natural habitat corridors, such as riparian strips (e.g. Lees & Peres 2007), rather than broader landscapes considered to be corridors. Experimental evaluations of corridor use by two forest bird species in Costa Rica showed that forest specialists preferred forested riparian corridors to live fence rows for movements across a deforested landscape (Gillies & Cassidy St. Clair 2008). Coffee plantations have been hypothesized to facilitate dispersal by forest-specialist birds across heterogeneous corridors, based on circumstantial evidence (Komar 2007). Within coffee plantations, few studies have looked at survivorship of birds or otherwise considered the quality of these habitats for bird survival (Komar 2006b). Cohen and Lindell (2004) suggested that a recently abandoned shaded coffee plantation, while attracting birds for nesting, may have been a sort of death trap, since the fledgling thrushes that they radio-tracked appeared to have lower survival than thrushes born in other habitats; nonetheless, alternative explanations, such as longer distance dispersal out of range of their tracking antennas, could explain the disappearance of their birds. Wunderle and Latta (2000) presented some intriguing survivorship data for three species of migratory warblers in coffee plantations of the West Indies. While the annual survivorship rates they reported seem comparable to natural habitats, they did not collect contemporaneous data in local natural habitats for comparison.

What habitats are acceptable as components of biological corridors for movement of forest biodiversity? Some definitions of a biological corridor have focused on continuous extensions of natural habitats (Rosenberg et al. 1997, Falcy & Estades 2007), while others have focused on the inclusion of intervened or disturbed habitats such as agroforestry (Miller et al. 2001, Harvey et al. 2008). Here I evaluate several key questions that will contribute to such a debate. For example, are some intervened habitats more valuable than others? Specifically, what are the relative survivorship rates for forest birds (generalist species) within the different habitats that integrate the corridor? Do migratory species, visiting for the winter, have higher survivorship and/or site fidelity in certain habitats? And do dispersing forest birds select certain habitats more than others within the corridor for movement across it? Since I used mist net capture data to consider these questions, first I evaluated the detectability (capture probability) of the study species, so that data from different habitat treatments can be compared and contrasted. One goal was to determine correction factors that may be necessary for comparison of bird capture rates among habitats within the Apaneca Biological Corridor.

4. Study Area

Geography and habitat availability in the Sierra de Apaneca

The study area comprised the entire Sierra de Apaneca mountain range in southwestern El Salvador, within the departments of Santa Ana, Sonsonate, and Ahuachapán. This area is the largest coffee-growing landscape in El Salvador, and contains some significant patches of natural forest located in three major protected areas: El Imposible National Park in the west, Los Volcanes National Park (within the Apaneca-Ilamatepec Biosphere Reserve) in the eastern-central portion of the range, and the San Marcelino Natural Area in the east, adjacent to the Lake Coatepeque caldera. The range is volcanic in origin, and contains a dozen volcanoes, including the Ilamatepec (or Santa Ana) volcano, which is the highest volcano in El Salvador (2365 m.a.s.l.) and which was active as recent as 2005. The area has been utilized previously for ornithology field studies, monitoring bird populations, and for studies of birds in coffee plantations (Komar & Herrera 1995, Komar 2006, Komar 2007, Komar et al. 2009).

The study area includes three ecoregions. The lowlands, up to about 700 m.a.s.l., belong to the Central American Dry Forests Ecoregion. The middle elevations, up to about 1900 m.a.s.l., belong to the Sierra Madre de Chiapas Moist Forest Ecoregion. The highest peaks contain cloud forest, and belong to the Central American Montane Forests Ecoregion. Coffee is cultivated from about 400 m to about 1700 m, and more than 90% of the area within that altitudinal band was long ago converted to coffee plantations. By September 2010, 11% of the existing coffee production area was certified as ecologically-friendly shade coffee, under the Rainforest Alliance Certified seal (Carlos Pleitez, pers. comm.). The study area is subject to a marked dry season, 6 months from December to May within which total rain fall is under 100 mm. During the remainder of the year, heavy monsoon-style rains keep soil moist; annual rainfall averages about 2000 mm, but in the wettest years can reach 3000 mm in the highest elevations of the mountain range.

Large sections of the Study Area are labeled as Key Biodiversity Areas and Important Bird Areas, because of the presence of globally-threatened amphibians and trees (Henríquez 2009), globally-threatened birds and regionally endemic birds (Komar & Ibarra 2009). Biodiversity analyses frequently identify the natural areas within the Sierra de Apaneca among the most important for conservation in El Salvador (Komar 2002, Greenbaum & Komar 2010).

For habitat availability, I consulted a recent land-use classification study for the entire study area, based on LandSat remote sensing (Ortega-Huerta et al. 2012). The study focused on distinguishing shaded coffee plantations from natural forest, and also on distinguishing closed-canopy coffee plantations (potential candidates for ecological certification) from more open canopy plantations, presumed to be mostly “technified” plantations with high inputs, and not potential candidates for coffee certification as currently implemented. The satellite imagery came from three separate dates, each in a different season, during 1998. The classification analysis used the combined images to help distinguish among habitat types.

Table 1. Relative availability of forest and coffee habitats in the Apaneca Biological Corridor.

Department	Forest (ha)	Open-Canopy Coffee (ha)	Closed-Canopy Coffee (ha)
Sonsonate	19,422	7,633	11,221
Santa Ana	11,476	9,731	21,532
Ahuachapán	16,503	9,319	13,925
Totals	47,401	26,683	46,677
Proportions	0.39	0.22	0.39

Fuente: Ortega-Huerta et al. 2012.

The best information available for habitat availability suggests that the Apaneca Biological Corridor includes approximately 120,000 ha of forests and coffee plantations (data extracted from Ortega-Huerta et al., 2012). The estimates of habitat distribution, based on remote sensing from 1998 LandSat imagery, suggest that more than 46,000 ha are natural forests, 47,000 ha are closed-canopy (shaded) coffee plantations, and 27,000 ha are open-canopy coffee plantations, equivalent to technified plantations (Table 1). The forests include the region’s protected areas, such as El Imposible and Los Volcanes national parks, and primary or mature forests along the ridges and peaks of the Sierra de Apaneca. However, about 10,000 ha of forests in Sonsonate in the adjoining Sierra del Bálsamo to the southeast are also included, and part of the area classified as natural forest are likely to be shaded coffee plantations in reality. Of particular relevance to the present study is the ratio of 1.75 ha of closed-canopy coffee to 1 ha of open-canopy coffee.

The aforementioned study did not present specific data on the relative availability of small forest fragments or patches of open areas, compared to either of the coffee habitats. Nonetheless, these habitats are visible in the land use classification map that was generated (Fig.1). Based on previous field experience in the study area, and inspection of the map in Fig. 1, I estimate that the availability of small forest fragments and patches of open habitat are roughly similar, whereas closed-canopy coffee plantation occupies at least 10 times as much area as either of those habitats within the corridor.

Site selection

In all, 50 field sites were established, including 10 control sites in large patches of natural forest (the control treatment) and 40 sites divided among 4 experimental treatments, each with 10 replicates. The experimental treatments are forest fragments (7–53 ha in size, mean 18.9 ha), Rainforest Alliance Certified coffee farms 12–85 ha in size, open-canopy technified coffee farms 5–105 ha in size, and open areas 1–13 ha in size, used for pasture (4 sites) or for basic grain production (6 sites, of which one was planted with sugar cane). The grain crops were maize rotated with beans.

The selection of the field sites, with the exception of control sites in the larger natural forests and of the treatment for Rainforest Alliance Certified coffee farms, was carried out by first randomly selecting a 9 km^2 block (each block with dimensions 3.6 x 2.5 km) located somewhere in the study area, and then searching for an appropriate property that met the requisites of the treatment. Certified coffee farms were also randomly selected but not by blocks. One block was randomly selected (without replacement within each treatment) for each field site, and then technicians searched within the selected block to find a site and obtain permissions from farm owners or managers. Only blocks located within the study area (outlined red in Fig. 2, above 400 masl and below 1300 masl) were used for site selection. The lower elevational limit was chosen because it is the lower limit of coffee production in the study area. The upper elevational limit was chosen so as to exclude most highland bird species from the study, and thus avoid the influence of the natural vegetation along the spine of the mountain range on the bird communities sampled within the study.

Prior to site selection, two other exclusion zones were mapped. First, areas within 3 km of the major forest areas (El Imposible National Park and San Marcelino Natural Area) were considered off limits, so as to avoid distance to natural forest being a major factor in the bird communities sampled. Second, areas between 800 and 900 m.a.s.l. were excluded, so as to cleanly separate the remaining field sites into a lower elevation group and a higher elevation group, each spanning a range of 400 vertical meters.

5. Methodology

At each of 50 sites (described in Study Area), permanently resident bird species (referred to hereafter as residents) and temporarily resident Nearctic-Neotropical migratory bird species (referred to hereafter as migrants) were captured in 10 mist-nets during 12 days (1000 net hours total, or 83.3 net hours per day). This trapping effort was spread evenly throughout 24 months, one day every two months, with one visit in each calendar month from March 2008 to March 2010, at each site. The birds were marked with uniquely numbered plastic or aluminum bands on their right tarsus. Hummingbirds were marked by clipping a tail feather (rectrix). Field work was carried out during good weather (no precipitation or heavy winds) and when sites were not subject to heavy presence of humans or livestock. The field teams captured 5,652 birds (including 394 recaptures). They also noted observations of birds around the netting sites.

Vegetation surveys

Vegetation data were collected from a total of 90 randomly placed transects of 0.1 ha (10 m x 100 m). Two transects were placed at each study site (just one transect at each natural forest site). The beginning of each transect was anchored at the center of the mist-net array, and the direction was selected randomly. Data were collected during the rainy season (June to November) at one transect per study site in each of four treatments (all but natural forest), such that I obtained data from one complete hectare per treatment. The process was repeated in the dry season (January through March), at all five habitat treatments, in different transects.

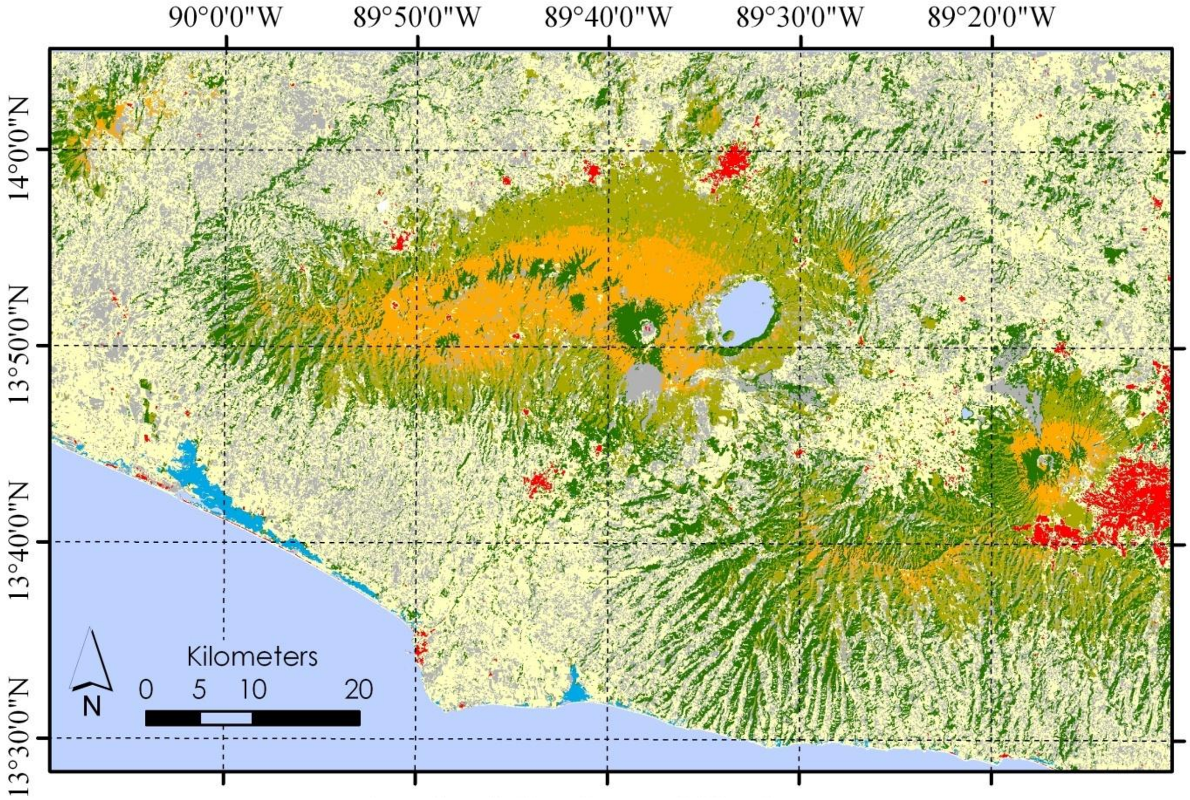

Figure 1. Remote sensing habitat classification of the Sierra de Apaneca (upper center part of image) and Sierra del Bálsamo (lower right part of image; Ortega-Huerta et al. 2012). Key to colors: Dark green=natural forest, Yellow=Open canopy coffee, Light green=closed-canopy coffee, Gray=lava flows or bare ground, Red=Urban, Blue=water, White=non-permanent agricultural. The large red area at the eastern edge of the image is the capital city of San Salvador.

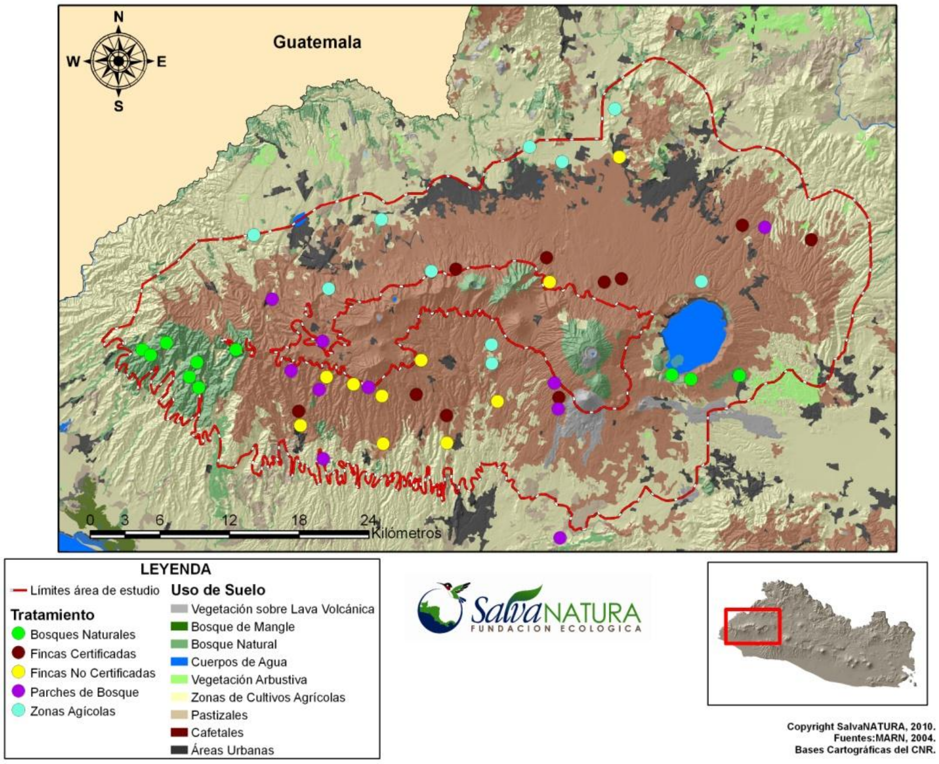

Figure 2. Delineation of the study area superimposed over an ecosystems map. Study sites are indicated, with separate colors for each of the five habitat treatments. Green dots: Natural Forest; brown dots: Certified Coffee; yellow dots: Technified Coffee; purple dots: Forest Fragments; light blue dots: Open Areas.

All trees with diameter at breast height (DBH) of 10 cm or greater were identified to morphospecies, and measured for tree volume, height (estimated by inspection), shade cover, and canopy structure. Morphospecies were recorded by local common names in the field, and are listed by those names in Appendix 3. Scientific names for trees were cross referenced with Linares (2005) and consulted with J. L. Linares to avoid misrepresentation of identifications; not all common names could be linked to a scientific name. Tree volume was estimated by applying a formula that incorporates DBH and height to estimate the overall above ground commercial wood volume (FAO 1968 cited by BIOFOR 2004). The formula is $\text{Volume}=0.0567 + 0.5074\ \text{DBH}^2 \times \text{Height}$. Shade cover was estimated by measuring the extension of each tree canopy from its trunk at four cardinal points around the trunk, and then taking the average as a mean radius, and using the mean radius to calculate the area of a circle around the trunk as an estimate of the shade cover provided by the tree when the sun is directly overhead. I estimated canopy structure by calculating standardized relative variation in tree height. For this calculation, I used the coefficient of variation (CV=100 SD /mean tree height; Sokal and Rohlf 1995, also used by Greenberg et al. 1997a and Komar 2006). Emergent trees were defined as trees >13 m tall, following Komar (2006).

For comparisons of vegetation parameters for all treatments except natural forest, the results from each of the two vegetation plots at each site were combined, since these plots likely lacked independence. For parameters of shade cover, % shade, and wood volume, comparisons were made on the grand means, since the raw data generated means with extremely high variances. Tree height, on the other hand, generated site means that were fairly similar, and the number of sites was too small to detect a significant difference between the grand means within the two coffee treatments. For the comparison among the coffee treatments, I present a t-test result on the mean, using the raw data (each tree was a sample, rather than each farm). For all comparisons among just two treatments, I conservatively present the results of two-tailed tests, although one-tailed tests (which would generate smaller P values) are justified, since the treatments represent a disturbance gradient and I always expected *a priori* one treatment to have consistently more vegetation than another. Principal Components Analysis of seven vegetation variables (canopy cover, mean tree height, tree density, tree species richness per transect, tree volume, CV of tree height, and abundance of emergent trees) was run on a correlation matrix, using Minitab 16 software.

Differences were considered significant when the alpha probability was <0.05. Comparisons across multiple treatments (i.e., including Forest Fragments, both types of coffee plantations, and Open Areas) were made with ANOVA tests. For comparisons of tree abundance, vegetated wind breaks in some of the coffee plantations were removed from the data set, because these highly trimmed rows of trees (*Croton* sp.) can be considered as shrubbery or part of the agronomy understory and artificially inflate tree abundance in plantations with relatively low density of shade trees. These narrow and low (<4 m) rows of densely planted trees contribute negligible amounts of shade cover to the plantations (Komar 2006).

Capture probability and survivorship

For the analysis of capture probability and survivorship, data from some sites were excluded because of irregularities in the timing of field visits or if effort was not distributed evenly among visits. Data from different sites were combined for estimating the overall capture probability and survivorship by habitat treatment. For residents, I used data from 34 field sites: 9 sites in Certified Coffee, 8 sites in Technified Coffee, 7 sites in Forest Fragments, 4 sites in Natural Forest, and 6 sites in Open Areas. For migrants, I used only data collected during the four winter months (November, December, January and February) when virtually all migrants have completed their long-distance journeys and are temporarily resident (Rappole 1995). At least some of the migrant species analyzed maintain local home ranges, and some of the migrant individuals defend winter territories. For the analysis of migrants, I used data from 38 field sites: 9 sites each in Certified Coffee and Technified Coffee, 8 sites in Open Areas, 6 sites in Forest Fragments, and 6 sites in Natural Forest.

Only birds that typically are found in the vertical strata below 2 m above ground, where the mist nets are placed, were considered for analysis of capture probabilities and survivorship. I.e., data from birds that are typically found in mid or upper forest canopies were excluded from the analysis. Birds considered non-resident in a particular habitat, such as forest specialists in open areas, or open area species in forests, were also excluded from analysis, as those individuals were assumed to be dispersers or transients. All birds in the study were classified as understory, midstory, or canopy species, based on the author’s extensive field experience in the study area. Unbanded birds, mostly hummingbirds, were not considered in most analyses, except where indicated otherwise.

Rare species (recorded <5 times) were also excluded from the analysis of survivorship and capture probabilities. Such species have negligible impact on the results. For the analysis of residents, 11 rare species (27 individuals) were excluded. For the analysis of migrants, 7 rare species (10 individuals) were excluded.

Residents were analyzed separately from migrants. Estimates of capture probabilities and bimonthly survivorship were generated by MARK, version 6.0 (White & Burnham 1999, White 2009). For migrants, I used MARK to estimate survivorship probabilities, and also contingency table analysis for hypothesis testing. I entered the data into MARK using 12 capture periods, but periods outside of the four-month winter period (November to February) were included with no data, unless the individual was also encountered during one of the winter months. This was to avoid bias caused by transients (passage migrants).

Habitat selection by putative dispersers

On a site by site basis, the resident (non-migratory) birds captured were classified as putative dispersers (or not). Individuals of species known to breed locally only in natural forest (forest specialists) were considered potential dispersers, especially if they were captured at a site where the species was not regularly observed or captured, and where the species was presumed not to breed. Individuals in breeding condition, that is with cloacal protuberance scores of 2 or higher (presumed males) or brood patch scores of 2 or higher (generally females) were not considered to be dispersers. I cross checked the date to confirm that such individuals were indeed captured during the breeding season. Local juveniles were also not considered to be dispersers. Young birds were only considered local juveniles when they were completely covered with juvenal plumage, having not yet carried out the first prebasic molt and thus were still within the first two months of life. These birds were assumed to still be accompanied by parents, captured near their natal site, and I cross checked the dates to confirm that such individuals were indeed captured during the breeding season. Individuals recaptured at a site after the visit of first capture (in a subsequent visit) were considered to be resident, and were never classified as a putative disperser.

The remaining individuals of resident bird species could have been dispersers, but to be conservative, I assumed that individuals of any species observed during more than one of the 12 site visits were part of the local bird community and not dispersers. Although observations were not a primary focus of the study, the field observers recorded all species observed during every site visit. Observations at the study sites, carried out by the banders, helped determine if some rarely captured species, such as canopy species, were normally present at the sites even if infrequent in the mist-netting samples.

Furthermore, I classified resident bird species as either forest specialists, forest generalists, or open area species (either specialists or generalists), following the classifications published in Komar et al. (2010). Some species classified as forest generalists by Komar et al. (2010) at the national level, were reclassified as forest specialists within the study area, because they are not normally found (or breed) outside of natural forests in the study area. These include Long-tailed Manakin (*Chiroxiphia linearis*), Orange-billed Nightingale-Thrush (*Catharus aurantiirostris*), Yellowish Flycatcher (*Empidonax flavescens*), Fan-tailed Warbler (*Basileuterus lachrymosus*), Streak-headed Woodcreeper (*Lepidocolaptes souleyetii*),Ochre-bellied Flycatcher (*Mionectes oleagineus*), and Slate-throated Redstart (*Myioborus miniatus*). Open area species were never classified as putative "forest" dispersers, although some were certainly dispersers and such individuals were occasionally found in forests, presumably during dispersive movements.

Forest specialists that breed only (or mostly) in the higher altitudes of the Sierra de Apaneca, and apparently wander or migrate downslope into the study area, were not classified as putative dispersers, as they may not have been using the biological corridor, and may have been captured at sites <3 km from their source population. These included White-faced Quail-Dove (*Geotrygon albifacies*), Emerald-chinned Hummingbird (*Abeillia abeillei*), Green-throated Mountaingem (*Lampornis viridipallens*), Mountain Elaenia (*Elaenia frantzii*), Yellowish Flycatcher (*Empidonax flavescens*), and Slate-throated Redstard (*Myioborus miniatus*), which were each captured just once or twice during the study.

"Forest generalists" are species that are widespread in a variety of wooded habitats, including plantations and disturbed areas such as urban parks. They are likely to breed across all habitat treatments studied, and are resident in the coffee plantations that occupy most of the study area. I tended to not classify "forest generalists" as dispersers, as the study hypothesis relates to forest specialists, but some generalists were probably dispersers as well, and in some rare cases, if generalists were marked at one forest site and recaptured at another site (regardless of habitat type), that demonstrated that they were “forest dispersers,” and such individuals were included in the count of putative forest dispersers. This occurred with individuals of Berylline Hummingbird (*Amazilia beryllina*), Blue-crowned Motmot (*Momotus momota*), and Rufous-capped Warbler (*Basileuterus rufifrons*). A generalist first captured at a non-forest site (of any habitat), and recaptured at a new site, although clearly dispersing, would not be classified as a putative forest disperser because the source population may not have been from a natural forest habitat.

Site fidelity and condition scores

In analyses of site fidelity, adults were birds aged as “after second year” or “after hatch year”. Birds aged as hatch year or second year were considered juveniles. Ages were determined in the field with the birds in the hand, using standard ageing criteria such as skull ossification, molt limits, plumage and soft part colors, feather condition, and rectrix shape (Pyle 1997). Each bird’s mass was measured in the field to the nearest gram on Pesola scales or electronic digital scales. Condition scores were calculated for 766 captures of the five most abundant winter visitor species (all n>80); these included Tennessee Warbler (*Oreothlypis peregrina*, n=106), Wilson's Warbler (*Cardellina pusilla*, n=133), Painted Bunting (*Passerina ciris*, n=82), Least Flycatcher (*Empidonax minimus*, n=112), Swainson's Thrush (*Catharus ustulatus*, n=333). Excluded were 33 individuals of these species that lacked mass or wing chord data. These species were reasonably distributed across all habitat treatments (Natural Forest n=177, Forest Fragments n=239, Certified Coffee n=199, Technified Coffee n=101, Open Areas n=50). Condition scores were calculated as mass divided by wing chord. Condition scores varied greatly by species, so they were standardized by dividing by each species’ mean condition score. The resulting standardized scores all had a mean of 1.

Statistical analyses

Statistical tests were carried out on Minitab 16 software, except where stated otherwise. Hypothesis tests were considered significant when *alpha* < 0.05. Stepwise multiple regression analyses were carried out to identify factors that may explain, or best predict, the abundance of groups of resident birds (forest specialists analyzed separately from forest generalists) and of migratory birds across the 50 study sites. The *alpha* to enter or remove variables in the models was 0.15. Response variables (abundance counts of birds) were square root transformed prior to analysis (untransformed variables given in Appendix 1). Predictor variables included patch size, tree abundance, tree species richness, percent shade cover, elevation, distance to urban areas, and distance to highways or paved roads (Appendix 2). A correlation matrix was prepared for these seven predictor variables, in order to remove highly correlated variables from the analysis. Correlations with coefficient $r > 0.75$ were considered for removal. The only highly correlated predictors were tree species richness with distance to urban area (r=0.751, P<0.001), and tree abundance with distance to urban area (r=0.98, P<0.001). All three predictors were considered important to the analyses, and therefore none were removed.

RESULTS

6. Vegetation

Vegetation parameters all varied significantly across treatments, increasing from lowest measurements in the Open Areas (grains and pastures treatment), to progressively higher measurements in Technified Coffee plantations, Certified Coffee plantations, Forest Fragments, and Natural Forest (ANOVA tests,

$P<0.001$; Table 2). The two coffee treatments on the whole were notably different, although some sites in the different treatments were similar in some measures (Fig. 3). All variables averaged higher in Certified Coffee. Two-tailed t-tests of differences among most variables in the coffee treatments were significantly different: % canopy cover (d.f.=18, $P=0.0005$), tree height (d.f.=1105, $P<0.00001$), tree density (d.f.=18, $P=0.002$), tree species richness per transect (d.f.=18, $P=0.012$), tree volume (d.f.=18, $P=0.027$), and coffee shrub density (d.f.=18, $P<0.00001$).

Measurements of canopy structure were highly variable and overlapped considerably for the two coffee treatments, such that the null hypothesis of equal means could not be rejected (d.f.=18, $P=0.664$). When canopy cover data from only the rainy season were compared, the difference was not significant (31% vs. 26%, $P=0.132$), presumably because several certified farms had just pruned the shade trees. Canopy cover in Certified Coffee increased during the dry season to 46%. The mean number of emergent trees (1.9 in Certified Coffee transects vs. 1.3 in Technified Coffee) also did not differ significantly ($P=0.684$). Similarly, the canopy cover provided by emergent trees (1.9% in Certified Coffee) was not different than the same measure in Technified Coffee (2.0%, $P=0.94$).

Differences in total tree species richness (Appendix 3) were not tested for statistical significance, as they are based on a survey of a single hectare (each hectare being 10 smaller samples combined), but tree species richness decreased along the disturbance gradient as expected (Fig. 4). As mentioned above, the difference in tree species richness between Certified and Technified Coffee was significantly different. The arboreal diversity, represented by both species richness and abundance, decreased along the gradient; a visual representation of the decline in arboreal diversity is given in the abundance profiles for each treatment (Fig. 5).

Table 2. Characterization of the vegetation in the five habitat treatments (10 sites per treatment, two vegetation plots per site).

Treatment	Plots (10 = 1 ha total area)	% canopy cover (± S.D.)	Tree density (Trees ha^{-1})	Tree species richness ha^{-1}	Mean tree species (0.2 ha^{-1})	Mean tree volume (m^3) (0.2 ha^{-1})	Mean tree height (m)	Mean max. tree height (m)	Canopy structure (Coeff. Var. on height)	Coffee shrub density (plants 0.1 ha^{-1})
Open Areas	18	7.2±6.7	96	21	4.3±2.2	5.7±4.8	5.4	8.3	26.1	0
Technified Coffee	20	26±7.7	207	35	6.7±3.2	7.3±4.1	4.9	9.5	32.6	433±32
Certified Coffee	20	40±6.9	320	60	13.6±7.1	14±8.2	5.8	11.4	35.5	198±15
Forest Fragments	20	82±13	475	107	23.6±7.6	20±13	6.4	16.6	46.1	0
Natural Forest*	10	83±20	633	114	27.3±5.3*	26±18*	8.6	26.0	61.4	0

*Just one vegetation plot (0.1 ha) per site, from dry season.

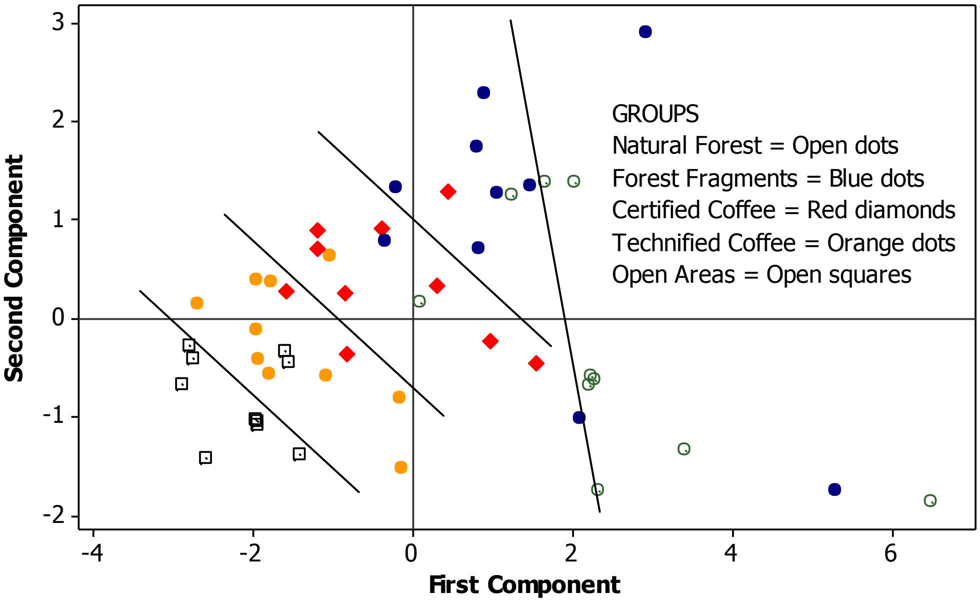

Figure 3. PCA score plot with seven vegetation variables indicates relatively little overlap among habitat treatments within the first two principal components.

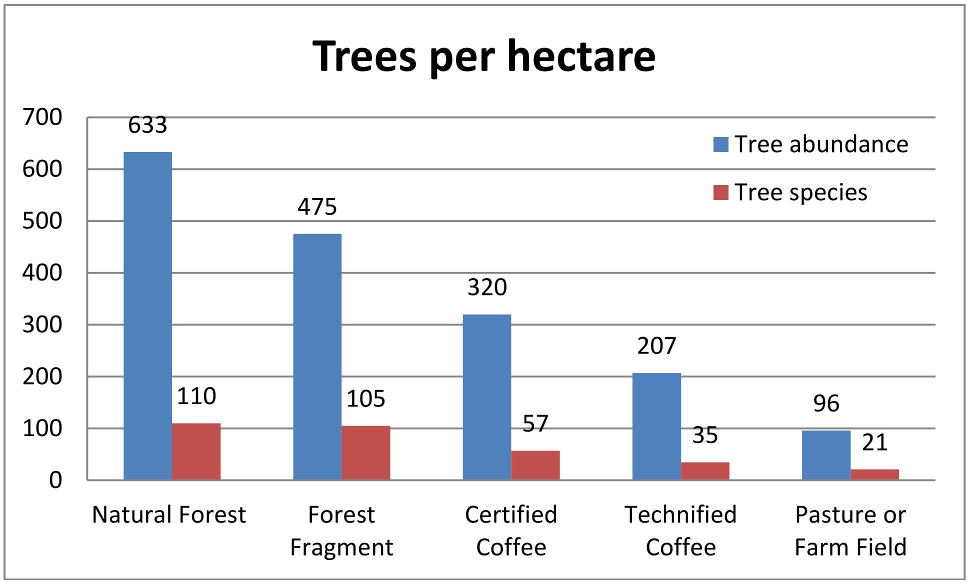

Figure 4. Tree species richness and tree abundance decreased with disturbance.

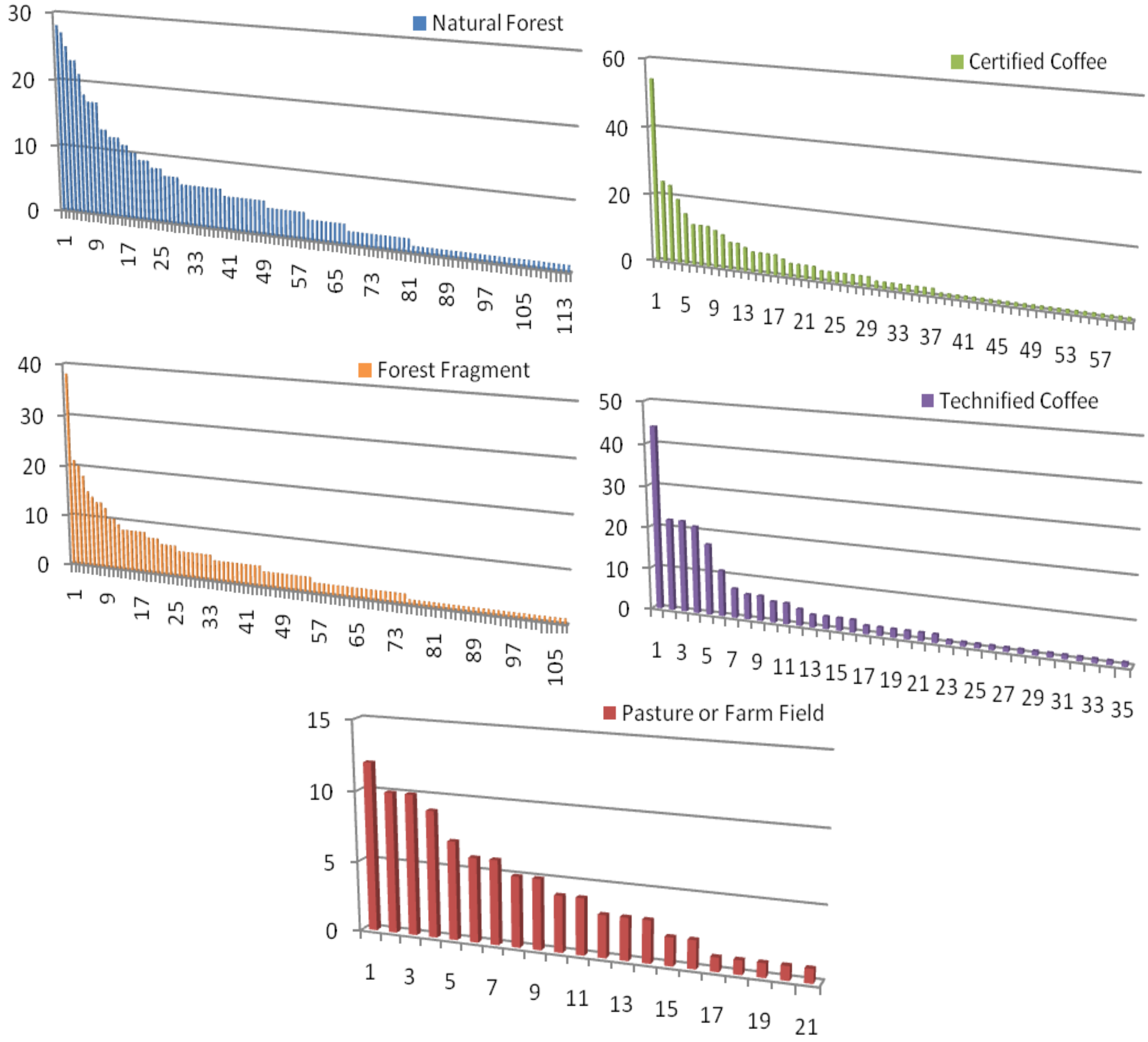

Figure 5. Abundance profiles for trees in the five treatments. The x axis presents the tree species in order from most abundant to least abundant. The y axis indicates the density (trees per ha) for each species.

7. Capture probabilities, survivorship, and site fidelity for resident birds.

I analyzed 1,178 capture histories of 22 understory, resident bird species (Table 3). A goodness of fit test on the capture histories, using Release version 3.0 (1997, combining results of Test 2 and Test 3), suggested that the overall data were fit for analysis (X^2=91.602, d.f.=90, P=0.433). The probability that a resident bird, known to be present (because it was captured formerly), would be detected (recaptured) in a posterior capture effort was similar among the five habitat treatments. A survivorship model generated by the program MARK {phi(g)p(g)}, where "g" refers to the habitat treatments or groups, suggested that capture probabilities (p) for all treatments were similar (range 3.4% to 4.2%, Table 4).

The dominant resident species in the disturbed habitat treatments (all but Natural Forest) was the Clay-colored Thrush (*Turdus grayi*), which formed up to 67% of the samples in some treatments. This generalist species was also common in the Natural Forest treatment, where it ranked third in abundance and provided 17% of all resident understory birds captured. In all, this one species generated 556 capture histories, so I analyzed it separately from the remaining species. A goodness of fit test on the capture histories, using Release version 3.0 (Test 2), suggested that the data were fit for analysis (X^2=4.807,

Table 3. Capture histories of resident understory bird species used to estimate relative capture probabilities among habitats in El Salvador.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Aimophila ruficauda	0	0	0	0	6
Basileuterus lachrymosus	22	5	0	0	0
Basileuterus rufifrons	35	56	65	38	5
Campylorhynchus rufinucha	1	13	14	21	1
Catharus aurantiirostris	5	7	0	0	0
Chiroxiphia linearis	28	12	0	0	0
Columbina inca	0	0	3	25	19
Columbina passerina	0	0	0	0	11
Columbina talpacoti	0	0	0	14	27
Crotophaga sulcirostris	0	3	1	6	12
Cyanocompsa parellina	4	5	0	0	0
Habia rubica	5	0	0	0	0
Leptotila verreauxi	3	6	8	10	2
Melozone leucotis	4	2	0	0	0
Mionectes oleagineus	3	12	0	0	0
Sporophila torqueola	0	0	0	0	11
Thryothorus maculipectus	10	6	0	0	0
Thryothorus modestus	1	1	1	0	2
Thryothorus rufalbus	11	13	0	0	0
Troglodytes aedon	0	4	4	0	4
Turdus grayi	27	116	146	228	39
Volatinia jacarina	0	0	0	0	35
Total counts	**159**	**261**	**242**	**342**	**174**
Species	14	15	8	7	13

Table 4. Detectability analysis for resident understory birds captured in mist nets, 83 net hours per day every two months during 24 months.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Sites combined for analysis	4	7	9	8	6
Capture histories	159	261	242	342	174
Recaptured individuals	25 (16%)	27 (10%)	19 (8%)	42 (12%)	10 (6%)
Recapture likelihood mean ± SE	3.7%±0.5%	4.2%±1.3%	3.4%±1.3%	3.6%±0.9%	3.4%±1.8%
95% credible interval	2.8%, 4.9%	2.3%, 7.5%	1.6%, 6.9%	2.2%, 5.9%	1.2%, 9.4%

d.f.=14, P=0.988). The model that worked best with this data set was {phi(.)p(g)}, in which survivorship was kept constant. Again, capture probabilities (p) for all treatments were mostly similar across habitats. Although the thrushes appear to have significantly higher capture probabilities in Technified Coffee than in some other treatments (Table 5), a test of between group differences, using Test 1 in Release version 3.0, indicated that there were no significant differences in either capture probability or survivorship (X^2=12.076, d.f.=20, P=0.913). The mean estimates of capture probability were lower than for all species combined, ranging from 0.6% to 2.9%.

The second-most abundant resident species was the Rufous-capped Warbler (*Basileuterus rufifrons*), with 199 individuals captured. The overall data appeared to be fit for analysis (X^2=13.607, d.f.=22, P=0.915; Test 2 in Release 3.0). As with the thrush, the model that worked best with this data set was {phi(.)p(g)}. Again, capture probabilities (p) for all treatments were mostly similar across habitats, with the apparent exception of Open Areas, although the sample for that habitat was too small (Table 5). Between-group differences (Test 1 in Release 3.0) indicated that there were no significant differences in either capture probability or survivorship (X^2=5.3463, d.f.=24, P=1.000). The mean estimates of capture probability were significantly higher than for the thrush (Table 5).

Table 5 also gives similar results for the group of 21 species combined, excluding Clay-colored Thrush, using the model {phi(.)p(g)}. A goodness of fit test on the capture histories, using Release 3.0 (combining results of Test 2 and Test 3), suggested that the data set was fit for analysis (X^2=61.360, d.f.=77, P=0.904). Although Open Areas appear to have lower capture probabilities, Test 1 in Release 3.0 indicated that there were no significant differences among the groups for capture probability or survivorship (X^2=18.522, d.f.=35, P=0.990).

Mean survivorship for resident birds was evaluated using the model {phi(g)p(g)} in Program MARK. The same model, described above, was used to calculate detectability for resident understory birds. Mean survivorship probability for resident birds, between bimonthly capture periods, ranged from 0.667 in Open Areas to 0.849 in Technified Coffee (Table 6). Survivorship at the Open Areas treatment was significantly lower than survivorship at Technified Coffee and Natural Forest treatments. Other two-way comparisons were not significantly different.

Table 5. Capture probabilities (detectability) for adult Clay-colored Thrushes, Rufous-capped Warblers, and all other species combined, at five habitats in El Salvador.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Clay-colored Thrush (*Turdus grayi*):					
Capture histories	27	116	146	228	39
Recapture likelihood mean ± SE	1.9%±0.4%	0.8%±0.5%	1.3%±0.5%	2.9%±0.7%	0.6%±0.6%
95% credible interval	1.2%, 2.9%	0.2%, 2.6%	0.6%, 2.9%	1.8%, 4.7%	0.1%, 4.5%
Rufous-capped Warbler (*Basileuterus rufifrons*):					
Capture histories	35	56	65	38	5
Recapture likelihood mean ± SE	6.3%±1.4%	5.8%±2.0%	6.2%±2.0%	5.4%±2.4%	NA
95% credible interval	4.1%, 9.6%	3.0%, 11.1%	3.2%, 11.6%	2.2%, 12.7%	NA
All species except *Turdus grayi*, combined:					
Capture histories	132	145	96	114	135
Recapture likelihood mean ± SE	5.5%±0.8%	6.6%±1.5%	5.4%±1.7%	6.2%±1.7%	2.6%±0.9%
95% credible interval	4.1%, 7.4%	4.2%, 10.3%	2.9%, 9.9%	3.5%, 10.6%	1.3%, 5.2%

Because two species dominated the sample of resident understory birds, I analyzed Clay-colored Thrush and Rufous-capped Warbler separately, using the model {phi(g)p(.)}, in which survivorship varied among the five habitat treatments (groups) and detectability (capture probability) was held constant (Table 6). High apparent survivorship for the thrush in Technified Coffee was significantly higher than in Certified Coffee, Forest Fragments, and Open Areas. The warbler showed no significant differences among habitat treatments, although the sample size was too small in Open Areas to obtain an estimate for that treatment. The group of 21 resident species combined, with the thrush excluded, provided similar results as the group of all 22 residents: Open Areas presented the lowest apparent survivorship (0.623). Instead of being significantly lower than just two of the treatments, it was significantly lower than three: all treatments except Technified Coffee (Table 6).

With resident birds, all individuals are expected to show site fidelity. Levels of site fidelity can still vary, however, especially if some sites are used more by dispersing individuals who are present only as transients. Lower site fidelity may also be correlated with higher mortality, i.e., lower survivorship. As expected, the proportion of recaptures (indicators of site fidelity) was positively (although not significantly) correlated with estimates of survivorship for resident understory birds (Pearson's correlation coefficient, *r*=0.77, P=0.12). The proportion of individuals recaptured in a posterior visit ranged from 6% to 16%, depending on the habitat (Table 4). These proportions seem low, considering that nearly 100% of the residents would be expected to be present on any given site visit, but clearly reflect the low capture probabilities for understory birds.

Table 6. Probability of bimonthly survival of resident understory birds at five habitats in El Salvador.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
All species combined					
Bimonthly Survivorship mean (± SE)	0.819±0.030	0.800±0.068	0.772±0.078	0.849±0.049	0.667±0.120
95% credible interval (%)	0.752, 0.871	0.636, 0.901	0.586, 0.890	0.727, 0.922	0.409, 0.852
All species except *Turdus grayi*, combined:					
Bimonthly Survivorship mean (± SE)	0.797±0.033	0.834±0.050	0.809±0.066	0.758±0.064	0.628±0.078
95% credible interval (%)	0.725, 0.853	0.713, 0.911	0.648, 0.907	0.612, 0.861	0.467, 0.765
Clay-colored Thrush (*Turdus grayi*):					
Bimonthly Survivorship mean (± SE)	0.857±0.043	0.659±0.131	0.735±0.089	0.940±0.045	0.428±0.283
95% credible interval (%)	0.750, 0.923	0.380, 0.858	0.532, 0.871	0.766, 0.987	0.072, 0.879
Rufous-capped Warbler (*Basileuterus rufifrons*):					
Bimonthly Survivorship mean (± SE)	0.846±0.043	0.862±0.062	0.842±0.067	0.732±0.106	NA
95% credible interval (%)	0.743, 0.913	0.691, 0.945	0.665, 0.935	0.487, 0.887	NA

8. Capture probabilities, survivorship, and site fidelity for migratory birds.

I analyzed 386 capture histories of 11 species of understory migrants for habitat-specific estimates of capture probability (Table 7). I generated estimates of capture probabilities, using Program MARK and selecting the model {*Phi*(.) *p*(g)} in which survivorship (*Phi*) is a constant, and capture probability (*p*) varies by habitat (group). A Goodness of Fit test (Release 3.0, Test 2) indicated that the data was fit for analysis (X^2=2.535, d.f.=13, P=0.999). The parameters generated by this model suggest that capture probabilities were similar among the Natural Forest habitats, Certified Coffee, and Open Areas, but significantly lower in Technified Coffee habitat (Table 8).

I analyzed the recaptures of migrants to obtain estimates of bimonthly survivorship. The model selected in MARK was {*Phi*(g) *p*(.)}, where survivorship (*Phi*) was allowed to vary with group (g=habitat treatment), and capture probability (*p*) was held constant. A Goodness of Fit test (Release 3.0, Test 2) indicated that the data was fit for analysis (X^2=2.535, d.f.=13, P=0.999). The parameter estimates of *Phi* for migrants were generally higher than for resident species, except in Technified Coffee (Table 9). As with the estimates of capture probability (Table 8), estimates of survivorship were similar among all habitat treatments except Technified Coffee, which was significantly lower.

Table 7. Capture histories of migrant understory bird species used to estimate relative capture probabilities among habitats in El Salvador.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Cardellina pusilla	3	9	33	14	2
Catharus ustulatus	28	37	22	6	0
Empidonax flaviventris	3	7	6	2	0
Empidonax minimus	4	2	30	13	15
Geothlypis formosa	0	4	0	1	0
Geothlypis tolmiei	0	0	1	2	5
Icteria virens	0	1	9	3	3
Passerina ciris	1	19	3	13	6
Passerina cyanea	1	3	0	3	12
Seiurus aurocapilla	10	9	9	4	1
Setophaga magnolia	4	1	9	11	2
Total counts	**54**	**92**	**122**	**72**	**46**
Species	8	10	9	11	8

Table 8. Detectability analysis for migrant understory birds captured in mist nets at 38 sites, during four days per site, spread across two winters.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Sites combined for analysis	6	6	9	9	8
Capture histories	54	92	122	72	46
Recapture events	6 (11%)	14 (15%)	14 (11%)	2 (3%)	4 (9%)
Within season site-faithful individuals	5 (9%)	4 (4%)	9 (7%)	2 (3%)	3 (7%)
Between season site-faithful individuals	1 (2%)	10 (11%)	4 (3%)	0	1 (2%)
Recapture likelihood mean ± SE	9.2%±1.8%	13.2%±3.9%	10.0%±2.9%	2.4%±1.7%	8.4%±4.2%
95% credible interval	6.1%, 13.6%	7.2%, 23.0%	5.6%, 17.1%	0.6%, 9.5%	3.0%, 21.2%

Table 9. Probability of bimonthly survival of migrant understory birds at five habitats in El Salvador.

Habitat	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Bimonthly Survivorship mean (± SE)	0.864±0.045	0.955±0.055	0.854±0.076	0.350±0.215	0.853±0.124
95% credible interval (%)	0.750, 0.930	0.636, 0.996	0.640, 0.951	0.078, 0.774	0.454, 0.976

The levels of site fidelity for migrant birds varied among treatments. The proportion of individual migrants recaptured at least one capture period (two months) after the original capture appeared to be larger in Certified Coffee than in Technified Coffee (11% vs. 3%, Fisher's Exact Test, P=0.054). In Forest Fragments, 15% of migrants presented site-fidelity, which was similar to Certified Coffee and significantly higher than Technified Coffee (P=0.008). The proportions of site-faithful migrants in Certified Coffee and Forest Fragments also appeared similar to the proportion (11%) in Natural Forest (the difference between natural forest and forest fragments is not significant, P=0.620). The Open Area treatment presented 9% site fidelity, and was not statistically different from any other treatment. These calculations of site-faithful migrants include individuals that were site-faithful either within a particular non-breeding season, or across different non-breeding seasons.

If only between-season recaptures (birds presenting site fidelity across successive non-breeding seasons in different years) are considered, Forest Fragments presented the most evidence of site fidelity, with 11% of individuals recaptured in a posterior non-breeding season, compared to 3% in Certified Coffee (P=0.047), 2% in Natural Forest (P=0.055), and 2% in Open Areas (P=0.100). The frequency of between-season site fidelity at Forest Fragments was most notably higher than at Technified Coffee (P=0.003), where no migrants were recaptured in a subsequent season (Table 8). The 10 individual migrants that returned to Forest Fragments in the second season included one Yellow-bellied Flycatcher (*Empidonax flaviventris*), five Swainson's Thrushes (*Catharus ustulatus*), three Ovenbirds (*Seiurus aurocapilla*), and one Painted Bunting (*Passerina ciris*). One of the Swainson's Thrushes was actually recaptured two seasons later, as it was captured on the first visit in March 2008 and again on the last visit in February 2010. The four individual migrants that returned to Certified Coffee sites in the second season of the study were two Least Flycatchers (*Empidonax minimus*) and two Wilson's Warblers (*Cardellina pusilla*). The one migrant that returned to an Open Area site in the second season was a Yellow-breasted Chat (*Icteria virens*). One Swainson's Thrush was recorded returning to Natural Forest in the second season.

9. Habitat selection by dispersing forest birds

During the study, 654 forest specialist birds (of 34 species, Appendix 4) were captured, and as expected, the great majority, 96.2%, were captured in Natural Forest (361 individuals) or Forest Fragments (268 individuals). In those two habitats, these birds are permanently resident, as was confirmed by recaptures during subsequent visits of marked birds of this group: 7% in Natural Forest and 14% in Forest Fragments. Of special interest to this study are the 3.8% of forest specialists that were captured outside of the two forest treatments, as well as 4.4% of the captures in the forest sites that appeared to represent species that were not regularly present at specific sites, which I supposed were dispersing birds (thus, "putative" dispersers). In all, 56 putative dispersing forest birds, including three forest generalist individuals documented moving from one site to another, were captured.

I eliminated from this group six forest specialist birds native to the high elevation forests at the top of the Sierra; these were probably altitudinal migrants and therefore not true users of the biological corridor under study. They included four birds in Forest Fragments (Emerald-chinned Hummingbird *Abeillia abeillei*, White-faced Quail-Dove *Geotrygon albifacies*, Yellowish Flycatcher *Empidonax flavescens*, Slate-throated Redstart *Myioborus miniatus*) and two birds in Certified Coffee (Green-throated Mountain-gem *Lampornis viridipallens*, Mountain Elaenia *Elaenia frantzii*).

The remaining 50 putative dispersing forest birds were distributed across all five habitat treatments: 14 in Natural Forest, 15 in small Forest Fragments, 13 in Certified Coffee, 6 in Technified Coffee, and 2 in Open Areas (Fig. 6, Table 10). Because I found similar capture probabilities for understory birds (described in a previous section) among the different habitat treatments, I was able to compare the capture rates of forest birds among the habitats, without applying correction factors for uneven detectability among habitats. The mean capture frequencies of the putative dispersers were tested with ANOVA; examination of residuals for the square-root-transformed response variable (counts of bird captures) indicated that model assumptions were slightly violated (Appendix 5). The null hypothesis was rejected for both habitat and altitude factors (P=0.022 and 0.019, respectively), but could not be rejected for a habitat-altitude interaction factor (Table 11). The higher elevation sites had more putative dispersers (mean 1.41 birds per site) than the lower elevation sites (mean 0.68 birds per site). Dispersers were recorded in all five high-elevation Technified Coffee sites, and in none of the low elevation Technified Coffee sites.

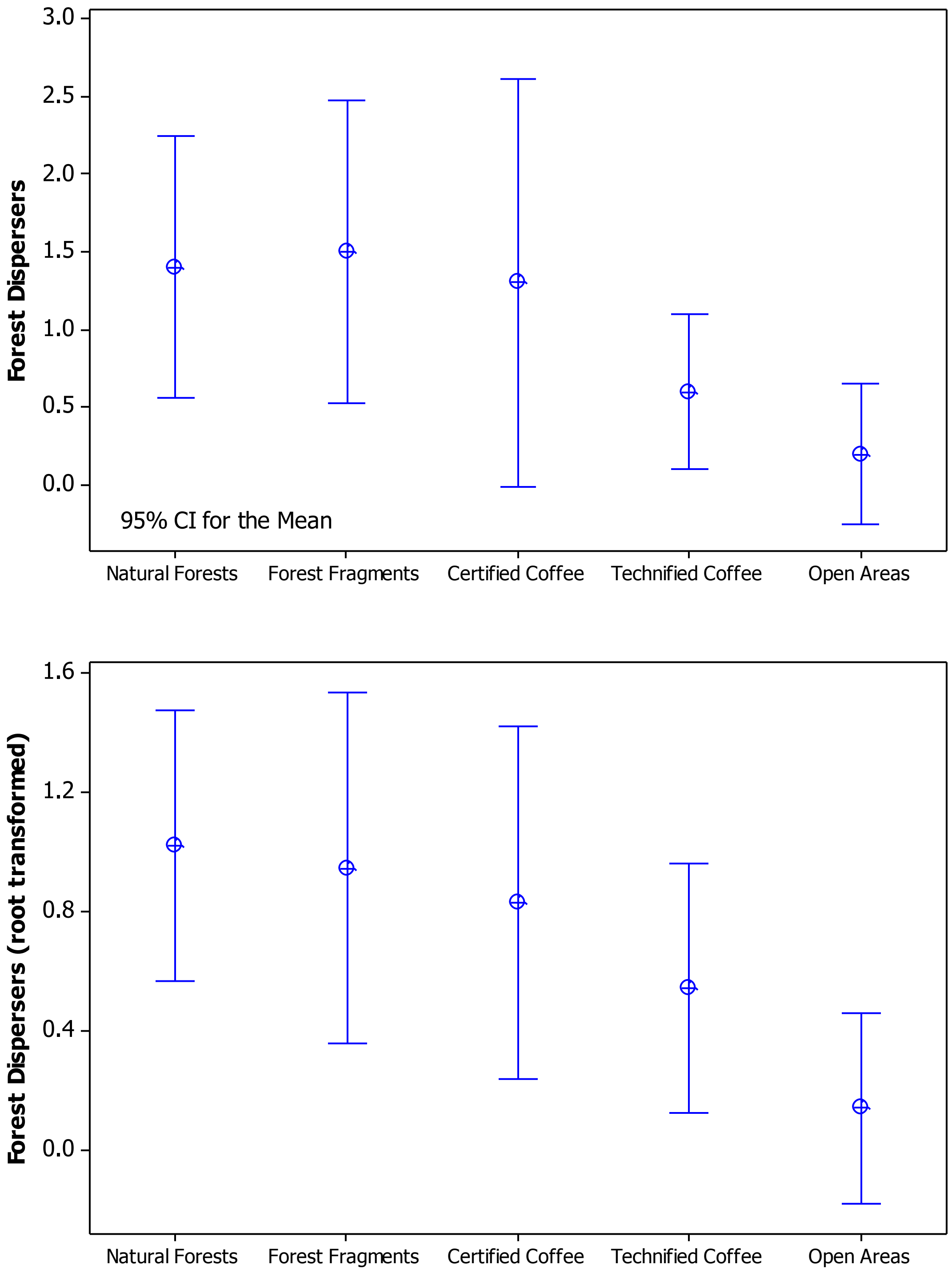

Figure 6. Mean capture rates (birds per 1000 net hours) for putative dispersing forest birds (untransformed data in top graph) across five habitats in the Sierra de Apaneca biological corridor.

Table 10. Captures of putative dispersing forest birds by habitat type during the study.

	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas
Blue Seedeater (*Amaurospiza concolor*)	2				
Yellow-billed Cacique (*Amblycercus holosericeus*)			1		
Bright-rumped Attila (*Attila spadiceus*)	1				
Rufous-capped Warbler (*Basileuterus rufifrons*)*	1				
Violet Sabrewing (*Campylopterus hemileucurus*)*	1				
Orange-billed Nightingale-Thrush (*Catharus aurantiirostris*)			2		
Blue Bunting (*Cyanocompsa parellina*)	2			2	
Ruddy Woodcreeper (*Dendrocincla homochroa*)	1	2			
Yellow-throated Euphonia (*Euphonia hirundinacea*)		1	1	1	
Fan-tailed Warbler (*Basileuterus lachrymosus*)	1		3	2	
Red-crowned Ant-Tanager (*Habia rubica*)		2			
Blue-throated Goldentail (*Hylocharis eliciae*)	1	2	3	1	2
Lesser Greenlet (*Hylophilus decurtatus*)		1			
Streak-headed Woodcreeper (*Lepidocolaptes souleyetii*)	1	2			
White-eared Ground-Sparrow (*Melozone leucotis*)			1		
Blue-crowned Motmot (*Momotus momota*)*		1			
Northern Bentbill (*Oncostoma cinereigulare*)	1	1			
Long-billed Gnatwren (*Ramphocaenus melanurus*)		1			
Eye-ringed Flatbill (*Rhynchocyclus brevirostris*)		1			
Banded Wren (*Thryothorus pleurostictus*)	1				
White-throated Robin (*Turdus assimilis*)	1	1	2		
Count	14	15	13	6	2

*Forest-generalist bird species documented moving from one forest patch to another.

Table 11. ANOVA results testing the variation of abundance of putative dispersing forest birds (square-root transformed) against habitat and altitude factors.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Habitat	4	5.1499	5.2884	1.3221	3.22	0.022
Altitude	1	2.4934	2.4333	2.4333	5.93	0.019
Habitat*Altitude	4	1.8103	1.8103	0.4526	1.10	0.368
Error	40	18.0933	18.0933	0.4523		
Total	49	27.3205				

DF=degrees of freedom; SS=sum of squares; MS=mean of squares; F=test statistic; P=probability.

The frequency of putative forest dispersers was clearly similar among Natural Forest, Forest Fragments, and Certified Coffee. How did these habitats compare with Technified Coffee and Open Areas? Examination of confidence intervals around individual means (Fig. 6), as well as results of two-sample T-tests (with d.f.=18), indicated that Forest Fragments had significantly more dispersers than Open Areas (P=0.014) but not Technified Coffee (P=0.223). Similarly, Natural Forest had significantly more dispersers than Open Areas (P=0.002) but apparently not Technified Coffee (P=0.096). Certified Coffee also had significantly more dispersers than Open Areas (P=0.033) but not Technified Coffee (P=0.383).

The 50 forest dispersers were captured in nearly every month, but mostly in the non-breeding season (September to March) and in the early breeding season (April and May). The peak frequency was in March (Table 12). There were no obvious differences in timing of dispersal movements between the different habitat treatments.

Table 12. Captures of putative dispersing forest birds by month and habitat type during the study.

	Natural Forest	Forest Fragments	Certified Coffee	Technified Coffee	Open Areas	All Sites
January	3	2	2	1	0	8
February	0	1	0	1	0	2
March	1	2	4	0	2	9
April	1	3	1	1	0	6
May	1	2	1	0	0	4
June	0	0	1	0	0	1
July	0	0	1	0	0	1
August	0	0	0	0	0	0
September	4	0	0	2	0	6
October	1	1	2	0	0	4
November	1	1	0	1	0	3
December	2	3	1	0	0	6

Note: Monthly effort was approximately equal in all treatments except Natural Forest, which was biased toward the dry season, November to March.

The best multiple linear regression model to explain the abundance of putative dispersers across the 50 sites selected just two predictor variables, tree species richness (P<0.001) and elevation (P=0.028), which explained 32.4% of the variance in the response variable, based on the adjusted R^2 value. Dispersers were more likely to be captured at sites with higher tree species richness and higher elevation. A simple linear regression model with just one predictor, tree species richness, explained 23.4% of the variance in the response variable (Fig. 7).

The best multivariate model to explain the abundance of all forest specialist birds at the 50 study sites contained three predictor variables, each highly significant (P<0.001) and positively correlated with the response variable. The model selected patch size, then percent shade cover, and then tree abundance; this model explained 75.8% of the variance in the response variable, based on the adjusted R^2 value. Individually, these predictor variables explained 41.9%, 57.5%, and 40.5% of the variation in the response variable (Figs. 8, 9, and 10).

Of particular interest for bird conservation planning may be the effect of patch size of small forest fragments on the abundance of dispersing forest-specialist birds. Although the patch size of the forest fragments varied considerably, from 7 to 53 ha, patch size appeared to have no influence on the abundance of putative dispersers (n=10, $F_{1,8}$=0.28, P=0.608) .

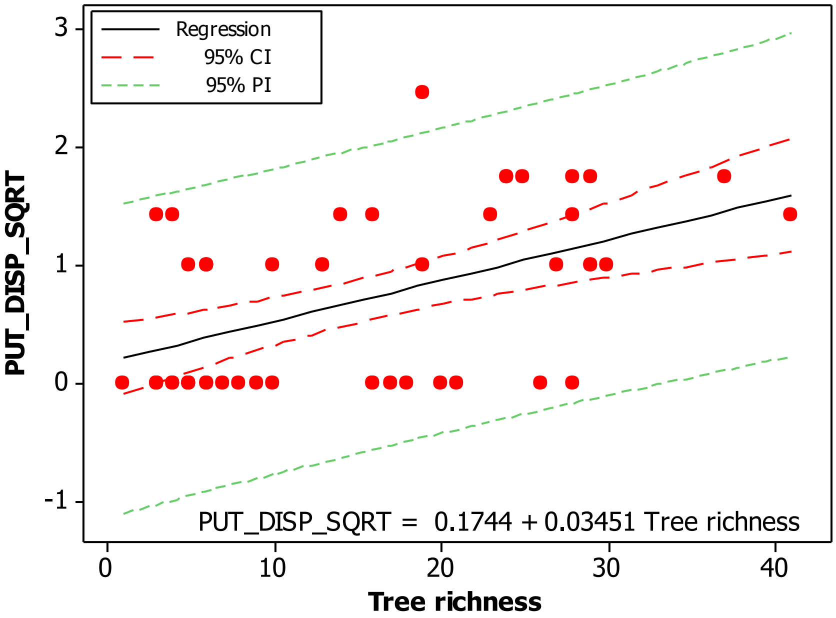

Figure 7. The best predictor variable for putative dispersing forest birds was tree richness (species per 0.2 ha plot), explaining 23.4% of the variance in the response variable.

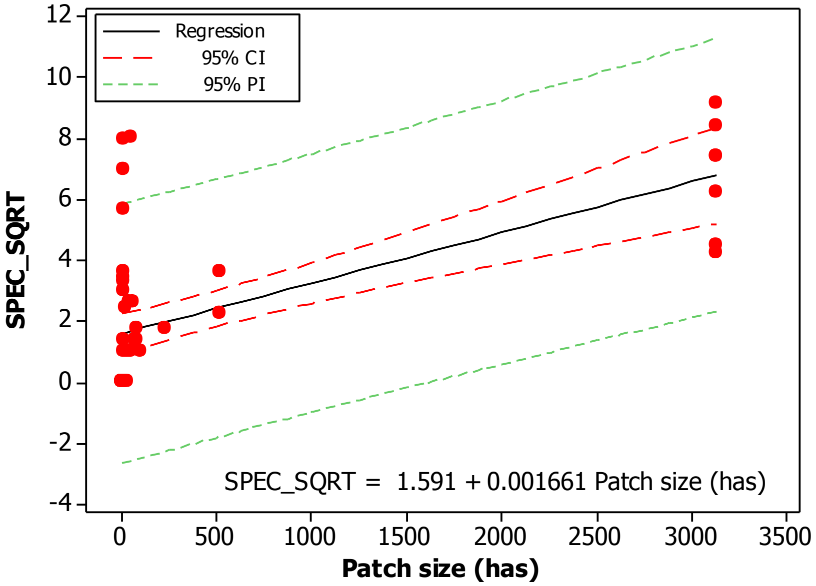

Figure 8. Patch size explained 41.9% of the variance in abundance of forest specialist birds.

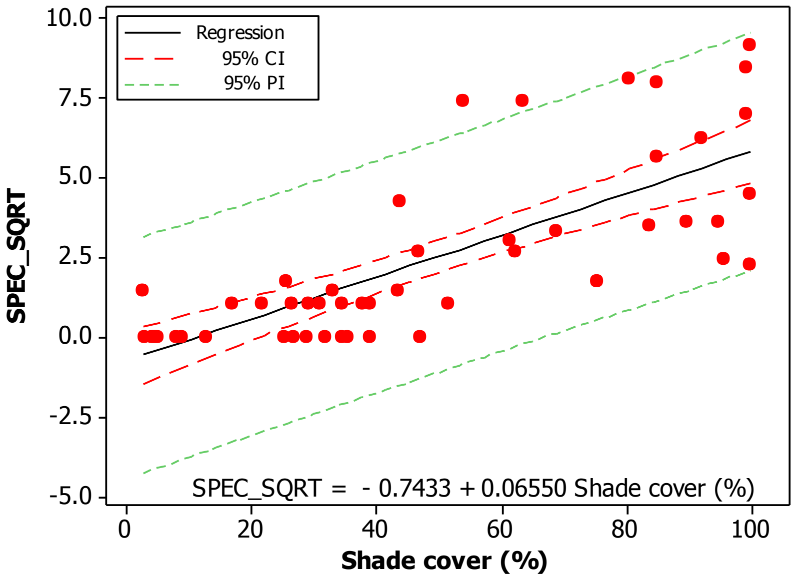

Figure 9. Percent shade cover explained 57.5% of the variance in abundance of forest specialist birds.

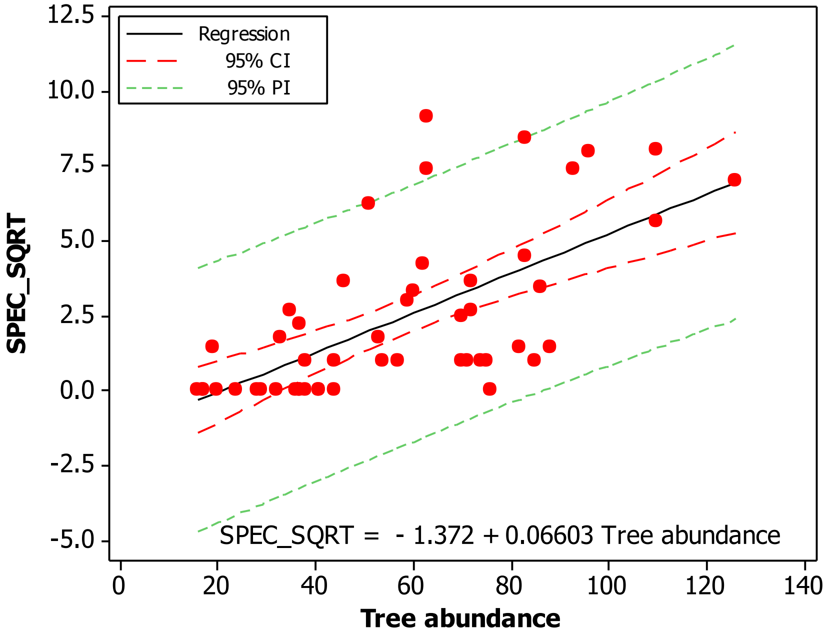

Figure 10. Tree abundance explained 40.5% of the variance in abundance of forest specialist birds.

10. Habitat selection by wintering migratory birds

The study captured 1605 individuals of 53 migrant species: 41 species that breed in North America and spend the winter in the study area (some individuals also pass through as transients; 1308 individuals and 57 recaptures); three breeding species that migrate to South America (214 individuals and 12 recaptures); and nine transient species that only pass through the study area en route between North American breeding grounds and South American wintering grounds (83 individuals, 0 recaptures). The null hypothesis is that migrants are not selecting specific habitats; given similar capture probabilities across habitats, they should present similar capture rates across the five habitat treatments. I examine below if the null hypothesis is supported by the data for each of these groups.

Of the 41 species of wintering migrants, 23 species each formed <1% of the wintering understory migrant community in the study area. Twelve species each formed >1% but <5% of the community, and six species each formed >5% of the community. The dominant migrant species were Ovenbird (*Seiurus aurocapilla*, 5.5%), Painted Bunting (*Passerina ciris*, 6.1%), Tennessee Warbler (*Oreothlypis peregrina*, 8.1%), Least Flycatcher (*Empidonax minimus*, 8.4%), Wilson's Warbler (*Cardellina pusilla*, 10.1%), and Swainson's Thrush (*Catharus ustulatus*, 25.0%).

Was abundance of migrants affected by habitat or by altitude class? In order to achieve homogeneity of variances and normally distributed residuals of the response variable, counts of wintering migrants (41 species combined) were square root transformed (Bartlett's test for equal variances on transformed variables P=0.37, Anderson-Darling test for normality on transformed variables, AD=0.408, P=0.34). The ANOVA indicated that the habitat effect was highly significant (P<0.001) whereas the blocking factor, altitude, was not significant (P=0.531). Two-way comparisons (Tukey method) indicated that Natural Forest, Forest Fragments, and Certified Coffee had similar abundances of migratory birds, and each of these habitats presented significantly higher mean counts of migrants than Technified Coffee and Open Areas. As evident in Fig. 11, the differences between the two coffee treatments was sizeable, and a t-test confirmed that the null hypothesis for just those two means should indeed be rejected (T=3.32, P=0.004, d.f.=18). Results for t-tests of the differences between Technified Coffee and Natural Forest (T=2.15, P=0.043) or Forest Fragments (T=2.53, P=0.021) were also significant.

A multivariate regression analysis of migrant abundance (capture rates) on seven predictor variables selected just one significant predictor: tree abundance (Fig. 12). The model explained 29.6% of the variance in migrant abundance, and was highly significant ($F_{1,48}$=21.57, P<0.001). The regression equation for untransformed variables is Migratory Birds=9.623 + 0.2912 Tree Abundance. No predictors explained the variance in the capture frequency of site-faithful migrants.

The three breeding migratory species are Sulphur-bellied Flycatcher (*Myiodynastes luteiventris*), Yellow-green Vireo (*Vireo flavoviridis*), and Blue Grosbeak (*Passerina caerulea*). Only five Sulphur-bellied Flycatchers were captured, three in Natural Forest or Forest Fragments, and two in Certified Coffee. Only 14 Blue Grosbeaks were captured, with similar capture rates in Certified and Technified Coffee as well as Open Areas. With so few captures, analysis of habitat preference is unwarranted. The Yellow-green Vireo was far more abundant, with 195 individuals captured (and 12 recapture events) spread across all five treatments. This species showed an apparent preference for Technified Coffee (90 captures, including 10 recaptures), vs. Certified Coffee (46 captures, including 2 recaptures), Natural Forest (37 captures), Forest Fragments (31 captures), and Open Areas (3 captures). In order to improve homogeneity of variance and normal distribution of residuals for counts of Yellow-green Vireo, the counts were square root transformed. Although the transformed response variable still violated test assumptions of normality

(Anderson-Darling test, AD=2.163, P<0.005), the ANOVA indicated that habitat significantly affected abundance of the vireo (P=0.004) whereas the blocking factor, altitude, was not significant (P=0.108). Two-way comparisons (Tukey method) indicated that only one pairwise comparison was significantly different: Technified Coffee had more vireos than Open Areas.

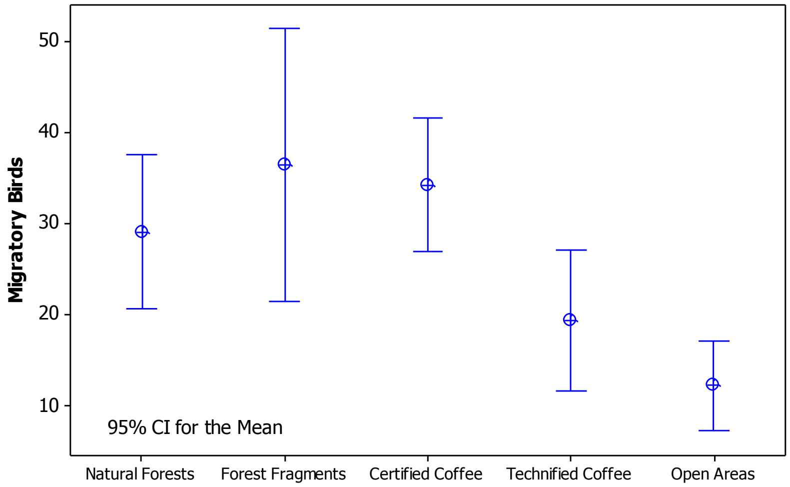

Figure 11. Variation in mean counts of wintering migrant birds (untransformed) captured in mist nets, 1,000 net-hours per site, in five habitats.

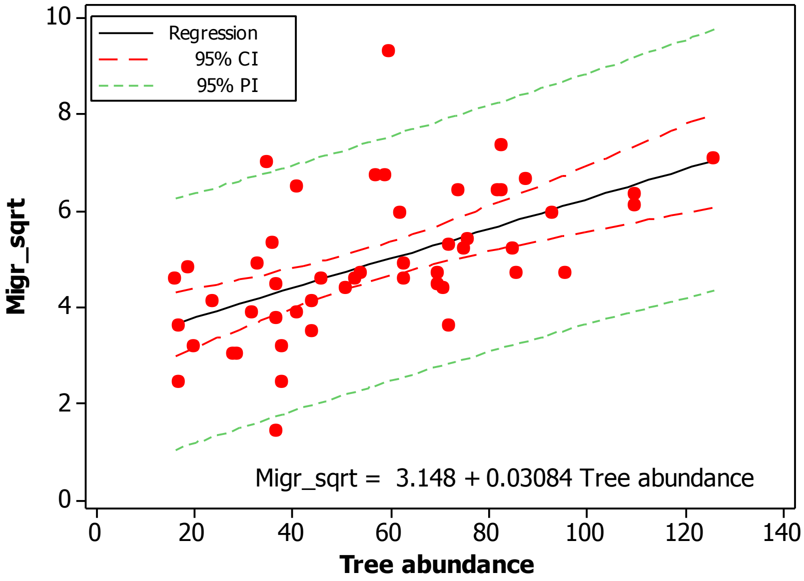

Figure 12. Tree abundance was the only significant predictor for abundance of wintering understory migratory birds.

Most of the transient species were rare, and only four of the nine transients were captured more than five times during the study. The Alder Flycatcher (*Empidonax alnorum*) and Willow Flycatcher (*E. traillii*), with eight and 12 individuals captured, respectively, were distributed more or less evenly across the five habitat treatments. Ten Mourning Warblers (*Geothlypis philadelphia*) were captured, five and four times in the Certified and Technified Coffee treatments, respectively, and once in Natural Forest. The Canada Warbler (*Cardellina canadensis*) was the only transient species that appeared to show a preference for any of the habitat treatments; 43 individuals were distributed across all habitat treatments, with 19 in Certified Coffee, 13 in Technified Coffee, 7 in Forest Fragments, three in Natural Forest, and one in Open Areas. Counts of Canada Warbler, square root transformed, still violated test assumptions (Anderson-Darling test for normality, AD=6.887, P<0.005; Levene's test for equal variances P=0.042), yet the ANOVA indicated that the habitat effect was significant (d.f.=4, P=0.010) whereas the blocking factor, altitude, was not significant (d.f.=1, P=0.544). Two-way comparisons (Tukey Method) indicated that two pairwise comparisons were significantly different: Certified Coffee had significantly higher counts of Canada Warbler than Open Areas and Natural Forest (although biases in timing of visits to Natural Forest sites may account for the apparent difference).

Is body condition of migrants better in Natural Forest or Certified Coffee than in Technified Coffee or Open Areas? Given the results presented in previous sections, indicating higher abundance, higher site fidelity, and higher apparent survivorship for migrants in forest and Certified Coffee habitats compared to Technified Coffee, here I evaluate if body condition indicators shed any light on the migrants' apparent choice for those habitats. In this analysis, "migrants" refers only to the set of five most abundant wintering species. These species include Swainson's Thrush (*Catharus ustulatus*, a frugivore in winter), Painted Bunting (*Passerina ciris*, a granivore in winter), Least Flycatcher (*Empidonax minimus*, an insectivore), Tennessee Warbler (*Oreothlypis peregrina*, a nectarivore and insectivore), and Wilson's Warbler (*Cardellina pusilla*, an insectivore).

I excluded May and August for having too few records (<5 each) and considered excluding other periods in which body condition may have been greatly influenced by migratory behavior (recent arrival or preparation for departure, when fat scores and mass may be expected to be especially low or high), nonetheless the standardized condition scores were not significantly influenced by month (one-way ANOVA, $F_{7,758}$=1.11, P=0.343, Fig. 13). Standardized condition scores were also not significantly affected by age, with four age classes considered: hatch-year, after hatch-year, second-year, and after second-year (one-way ANOVA, $F_{3,751}$=0.52, P=0.669).

Habitat significantly affected standardized condition scores for migratory birds ($F_{4, 761}$=5.75, P<0.001), although habitat explained only 2.4% of the variance. Natural Forest, Technified Coffee, and Certified Coffee presented generally low scores, whereas the highest mean condition score was in Forest Fragments, followed by Open Areas (Fig. 14). The Tukey grouping method indicated that Open Areas were not significantly different than any other habitat, but Forest Fragments presented significantly higher condition scores than all other habitats except Open Areas.

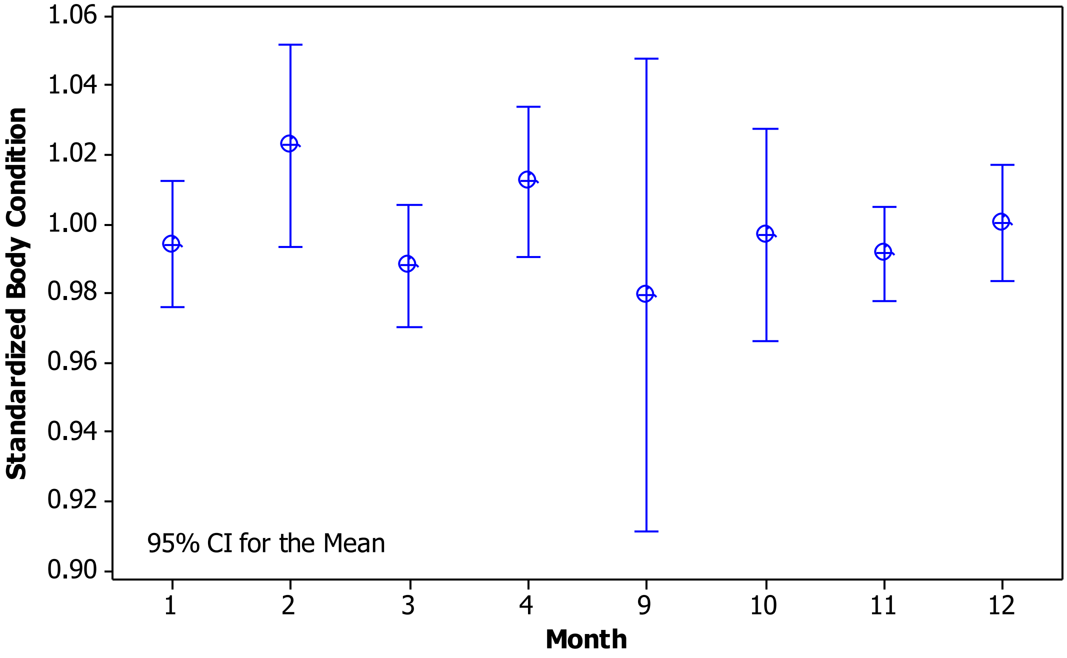

Figure 13. Comparison of mean standardized condition scores for winter visitor migrant birds in El Salvador, by month (1=January, 12=December).

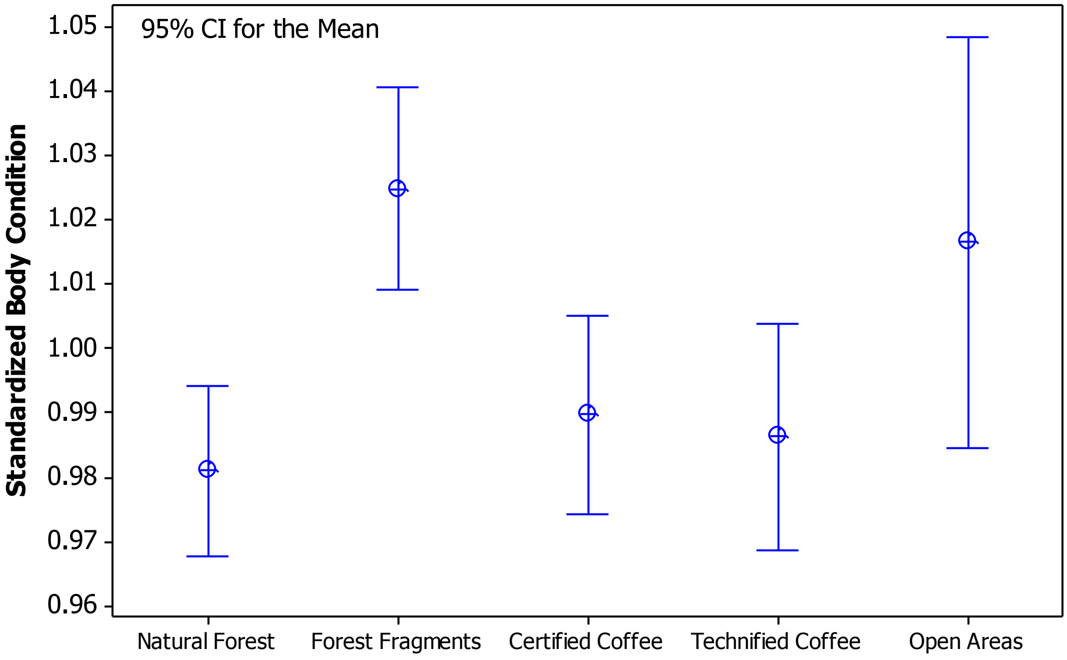

Figure 14. Comparison of mean standardized condition scores for winter visitor migrant birds in El Salvador, by habitat.

11. Habitat selection by resident forest generalist birds

The study captured 2,642 individuals of 50 forest generalist bird species (listed in Appendix 4). Not included in this count are captures of 24 bird species classified as “open generalists”, which are species resident in a variety of open habitats but rarely or never in forest habitats. Because I determined that capture probabilities for understory species were similar across the five habitat treatments, I can make meaningful comparisons of relative abundance in these treatments without adjusting the data with a correction factor. The null hypothesis is that resident generalist forest species are not selecting specific habitats. Given similar capture probabilities across habitats, they should present similar capture rates across the five habitat treatments. I examine below if the null hypothesis is supported by the data.

Of the 50 species of forest generalists, 30 species each formed <1% of the community of understory forest generalist birds in the study area. Sixteen species each formed >1% but <5% of the community, and four species each formed >5% of the community. The dominant forest generalist species were Cinnamon Hummingbird (*Amazilia rutila*, 6.6%), Berylline Hummingbird (*Amazilia beryllina*, 7.5%), Rufous-capped Warbler (*Basileuterus ruficapillus*, 12.8%), and Clay-colored Thrush (*Turdus grayi*, 26.7%).

The effects of habitat and altitude class on the counts of resident generalists were considered using ANOVA. Square-root transformation of the counts (50 species combined, not including recaptures) satisfied assumptions of homogeneous variances and normally distributed residuals (Appendix 5). Habitat type affected the counts significantly (P<0.001) whereas the blocking factor, altitude, was not significant (P=0.417), nor was there an interaction affect between habitat and altitude (Table 13). Two-way comparisons (Tukey method) indicated that all habitats except Open Areas had similar abundance of forest generalist birds (Fig. 15). As evident in Fig. 15, however, the differences between Natural Forest and the other treatments was sizeable, with fewer resident generalist birds captured in Natural Forest, and a one-way ANOVA, excluding data from Open Areas, determined that capture rates were indeed significantly affected by habitat within the four remaining habitat types ($F_{3,36}$=2.95, P=0.046).

These results show that resident generalist birds were similarly abundant in both types of coffee habitats as well as Forest Fragments. To consider whether the general abundance is year-round in these habitats, or potentially affected by seasonal variation, I also analyzed variance in resident generalist birds in breeding condition (adults with brood patches or cloacal protuberances). However, no habitat effect on abundance of breeding birds was discernible ($F_{4,45}$=2.03, P=0.106).

Table 13. ANOVA results testing the variation of abundance of generalist forest birds (square-root transformed) against habitat and altitude factors.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Habitat	4	68.194	67.471	16.868	7.74	0.000
Altitude	1	1.522	1.465	1.465	0.67	0.417
Habitat*Altitude	4	11.981	11.981	2.995	1.37	0.260
Error	40	87.175	87.175	2.179		
Total	49	168.872				

DF=degrees of freedom; SS=sum of squares; MS=mean of squares, F=test statistic, P=probability.

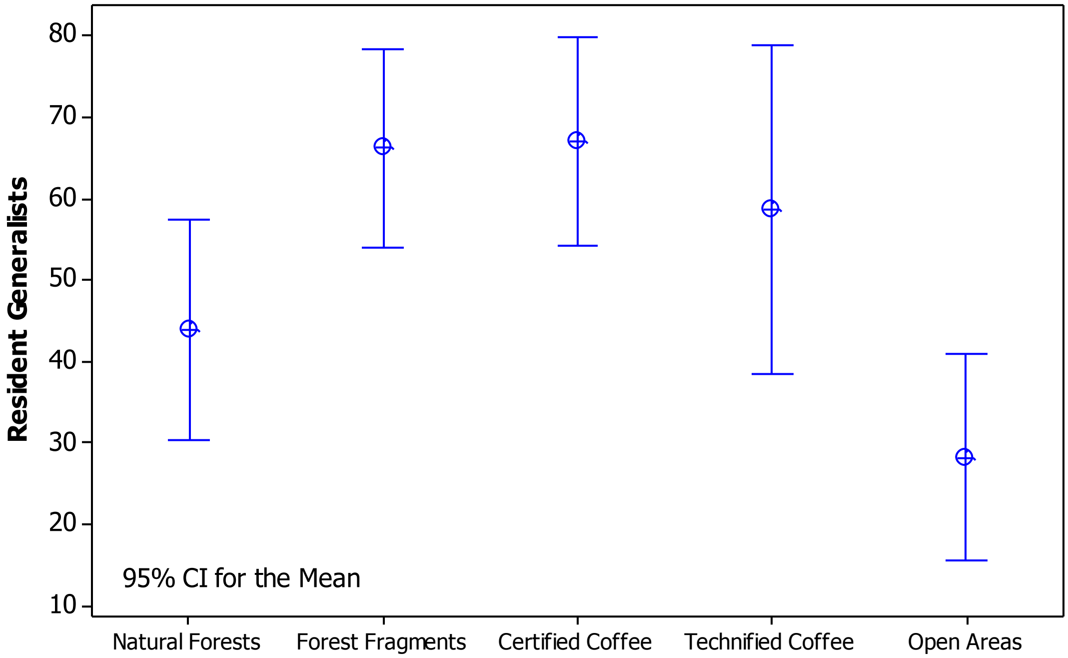

Figure 15. Relative capture rates of forest generalist birds (untransformed, birds per 1000 net hours) in the study area.

The similarity of overall abundance of breeding birds across the habitats studied could still be masking differences that may be discernible by evaluating proportions of the bird community that are detected to be actively breeding. The proportion of forest generalists captured either as an adult in breeding condition or a locally born juvenile might be expected to be higher in a "bird-friendly" habitat (although not necessarily, see Discussion). The proportion of breeding individuals captured in Technified Coffee (not including recaptures) was 34%, which was similar to the proportion of breeding generalists captured in Natural Forest (33%), Open Areas (33%), and Forest Fragments (30%). Surprisingly, it was significantly higher than the proportion of breeding generalists captured in Certified Coffee (24%, Fisher's Exact Test, P=0.00015), which was a significant difference in the opposite direction than expected.

What were the best variables for predicting the abundance of resident generalist forest bird species? Multivariate regression selected a two-predictor model, with shade cover being the strongest predictor (T=3.88, P<0.001) followed by patch size (T=-3.45, P=0.001). Abundance of forest generalists was positively correlated with shade cover, but negatively correlated with patch size. The two-predictor model explained 25.7% of the variance in counts of understory resident generalist birds.

12. Discussion

Vegetation

As expected, the shade canopy layer was markedly and highly significantly different among Open Areas (mean 7% cover), Technified Coffee (mean 26%), Certified Coffee (mean 40%), and Forest Fragments (mean 82%). Of particular interest to the present study, however, was the lack of significant difference in canopy cover between Certified and Technified Coffee farms during the rainy season, when many of the farms have had their shade trees recently pruned or pollarded. Although canopy cover at that season averaged greater in the certified plantations (31% vs. 26%), variability was high in both types of farms and the difference was not significant. The low canopy cover in certified plantations was surprising, as I expected all certified plantations to have >40% shade, the recommendation of the Rainforest Alliance Certified program (RAS 2009). During the rainy season, only two of the ten certified transects had canopy cover >40%, and six transects had canopy cover <30%. This low level of canopy cover may reflect the practice of the Rainforest Alliance certification program to permit the entrance of farms that are in the process of changing practices to comply with certification norms, or may be related to how canopy cover was measured. It may also reflect a lack of understanding or respect for the certification criteria on the part of the farm managers, some of whom may be thinning their shade trees more than they should as certified farms. During the dry season, however, canopy cover averaged 46% on certified farms.

Prior to the selection of field sites, I expected technified transects to have <25% shade, and indeed technified sites were selected during the dry season of 2007–2008 based on the appearance of low shade and the confirmation of farm managers of high input use. Nonetheless, only six out of ten transects had canopy cover <25%, and the mean canopy cover was actually slightly above 25%. I considered the possibility that wind breaks in the technified plantations may have “artificially” inflated the measurement of canopy cover, but only half of the technified transects contained wind-breaks, and they contributed insignificantly to the canopy calculation. Despite the similarity in canopy cover among the two coffee treatments during the rainy season, canopy cover was significantly different during the dry season, so much so that when data from both seasons were combined, the means among the two coffee treatments were significantly different.

Six vegetation parameters were significantly different among the two coffee treatments, while four were not. Those four include maximum tree height and coefficient of variation in tree height (a measure of canopy structure), although Certified Coffee tended towards higher trees and greater canopy structural variation. In fact, the parameter mean tree height was significantly different among the two treatments. Two other parameters were essentially similar among the two treatments: abundance of emergent trees and proportion of shade provided by emergent trees.

Biological differences among the two types of coffee plantations were evident in the bird communities. The capture rate of open area bird species in Technified Coffee was 7.0 birds per 1000 net-hours, whereas the capture rate in Certified Coffee was just 2.1 “open area” birds per 1000 net hours. For comparison, Forest Fragments presented a capture rate of 0.7 “open area” birds per 1000 net-hours.

The estimates of tree species richness per hectare in all treatments are conservative, because I used morphospecies (identified with the aid of a field guide, Monro et al. 2001), rather than collecting samples and obtaining herbarium-confirmed botanical identifications. Thus, some cryptic species may be missing. The results, nonetheless, demonstrate broad differences in biodiversity among the sample treatments. I found more tree biodiversity than expected in both Technified Coffee (35 species) and Open Areas (21 species). Most of the richness in Open Areas was found in live fence rows. Thus, 21 species per ha represents a baseline equivalent to the lowest biodiversity that a disturbed patch in the study area would have, and any kind of conservation program or sustainable agriculture certification should strive to improve on that figure. The Certified Coffee farms showed a total diversity improvement of 25 additional tree species (60 species per ha). The Rainforest Alliance Certified criteria (RAS 2009) suggest that a sustainable farm should have >12 native tree species per hectare, a threshold that appears to be too low in the study area. I suggest that the criterion could be changed to "at least 10 native tree species per hectare more than a local baseline typical of highly disturbed areas".

The tree species richness found in the two coffee plantation treatments (35 and 60 species per hectare, respectively) can be compared with previous studies. In the same general area of southwestern El Salvador, Komar (2006) characterized tree richness at 18 coffee plantations with a range of vegetation cover; richness on 0.5 ha plots at each plantation ranged from 4 to 39 species. Soto-Pinto et al. (2000) documented shade trees in coffee plantations of Chiapas, Mexico, finding 61 species providing shade, and 260 trees per ha. In comparison, I report 320 shade trees per ha in the certified plantations, and 207 shade trees per ha in the technified plantations. Monro et al. (2001) documented a total of 261 tree species from shaded coffee plantations in El Salvador.

Also interesting is a comparison of vegetation in the study area with the Rainforest Alliance certification criteria for tree density and emergent trees in coffee plantations. In the past, the criteria have proposed a minimum threshold of 70 shade trees per ha and 20% of shade provided by emergent trees (Rainforest Alliance 2002, 2005). For the set of certified farms in the present study, the tree density threshold was far surpassed (320 shade trees per ha). The lowest density farm had 130 trees per ha. Among the non-certified, "technified" plantations (some of which may qualify for certification), the overall density was 207 shade trees per ha, and the minimum was 110. Even Open Area transects, used for grain production and pastures, had a density of 96 trees per ha, although most were small trees planted in live fence rows. These data demonstrate that simple density of trees can be a misleading indicator of vegetation cover, because of great disparity among tree sizes. The emergent trees on the certified farm plots, defined as trees >13 m tall (following Komar 2006), provided just 9.4% of the total shade production (from 14 trees per ha), less than half of the criteria threshold of 20%. On the non-certified plots, there were fewer emergent trees, just 7 per ha, and these provided 10% of the total shade production.

Capture probabilities and survivorship

In order for capture rates to be compared among habitats, the probabilities of capturing birds that are truly present must be similar in each habitat (Remsen & Good 1996). Otherwise, a correction factor should be applied to adjust for different capture probabilities. Theoretically, different habitats could have different capture probabilities because of differences in density of vegetation that affects the ability for birds to see and therefore avoid capture. Variation in habitat structure could also affect the height at which birds fly, that would also affect the likelihood of flying into a net. Nonetheless, Bayesian probability models that considered both survivorship and capture probability indicated that the data sets from each habitat treatment were indeed comparable, because the capture probabilities were similar across treatments, especially for resident birds. The data set for migrants was smaller, and the conclusions less robust, but nonetheless, the capture probabilities appeared to be similar across all habitats, with the exception of Technified Coffee. With no clear evidence to reject the null hypothesis of equal capture probabilities across habitats, for both resident birds and migrants, I thus compared habitat use based on capture rates and apparent avian survivorship across the five habitats for various bird species.

Capture probabilities for resident understory species were not homogeneous across species. The detectability of Clay-colored Thrushes was significantly lower than Rufous-capped Warblers across all habitats. This difference is not surprising, for two reasons. First, Clay-colored Thrushes have a broader vertical niche, often moving in the tree canopies well above the understory where the traps are located. They also have a broader ecological niche, consuming fruits in tree canopies, shrubs and from the ground, as well as consuming invertebrates. Rufous-capped Warblers are thought to be strictly arthropod gleaners found almost exclusively in the understory. The broader vertical niche of the thrushes is consistent with lower detectability in mist nets. Second, Clay-colored Thrushes are often gregarious in the non-breeding season, and local migratory movements are suspected (Dickey and van Rossem 1938). While I could not detect local migratory movements, it is certainly possible that individuals may wander widely in the non-breeding season in search of fruit, which would greatly reduce detectability at a specific capture site. Such behavior is not suspected for the warblers.

Of greater relevance to the present study was the variation in detectability (capture probability) across habitats, rather than across species. While all species combined did not demonstrate differences among habitats, the thrush (but not the warbler) showed some significant differences in detectability between habitats. Clay-colored Thrushes were more detectable in Technified Coffee than in Certified Coffee and in Forest Fragments. Presumably, thrushes are about twice as likely to be captured in the understory in Technified Coffee than in Certified Coffee habitats, and three times as likely than in Forest Fragments. A possible explanation may be that the thrushes have greater feeding opportunities above the understory in Certified Coffee and in Forest Fragments, which would reduce the probability of capture in those habitats in the understory.

In contrast to the results for the resident Clay-colored Thrush, the MARK model used to compare capture probabilities of understory migrants among treatments indicated that detectability in Technified Coffee appeared to be about four times lower than all other habitats. That result can be used to generate a correction factor for abundance estimates of migrants in Technified Coffee. The mean estimates for capture probability suggest a correction factor of 4.17 for Technified Coffee capture rates of migrants, so that they are comparable to the capture rates for Certified Coffee. However, the range of possible correction factors based on the 95% confidence limits for estimates of capture probability in each of the coffee treatments, is 0.6 to 28.5. This large range includes correction factors in both directions (i.e., below 1 and above 1), which degrades confidence in using a correction factor. Considering that no significant differences in capture probabilities were detected for resident understory birds (all species combined), and that no differences were detected for migrants in the other habitat treatments, the apparent difference for Technified Coffee may have been a case of Type I error. This assumption is supported by the lack of expected differences in capture probability. A correction factor was not applied during the analysis.

Apparent survivorship is a useful indicator for habitat quality (Latta & Baltz 1997). Other indicators often used, such as breeding success and abundance or density, can be misleading. A site may be attractive for breeding because of abundant nesting sites, but offer low long-term survivorship. High population densities may reflect a series of situations that are negative for survivorship, such as overpopulation or predation traps (van Horne 1983). I use the term “apparent” to recognize that lower survivorship may reflect either higher mortality, higher emigration rates, or a combination of both. Either way, this statistic can be interpreted as a measure of habitat quality.

Although resident birds appeared to survive equally well in Technified Coffee as in other habitats, Technified Coffee presented the lowest apparent survivorship for migrant birds. Ecological scenarios that explain low apparent survivorship for migrants include higher mortality from ingestion of agrochemicals, higher predation rates because of sparser vegetation, and higher emigration because of poor foraging conditions. Perhaps the habitat appears attractive at first, such that many migrants visit the habitat (and are caught in researchers’ mist nets) but when they discover that food resources are low, they quickly move on to “greener pastures”, generating low apparent survivorship statistics and low site fidelity statistics. A surprising result is that apparent survivorship of migrants in the Open Area treatment was comparable to other habitats, including Natural Forest, when it would be expected to be comparable (or worse than) Technified Coffee. However, this result is consistent with the hypothesis that heavy agrochemical use in Technified Coffee (but not in Open Areas) may cause the apparent low survivorship. Both Open Area and Technified Coffee parameter estimates for migrants had very wide 95% confidence intervals (Table 9).

The survivorship rates for both Technified Coffee and Open Area habitats may be artificially increased by the inclusion in the data set of birds well adapted to open areas, such as ground doves (*Columbina* spp.). These species are considered open-area generalists, but only occasionally occupy disturbed forest habitats. For a truer evaluation of a completely disturbed habitat, compared with the original natural forest habitat, it would be necessary to exclude from the data set the species that are principally adapted to open areas, and only compare the survivorship and capture probabilities for forest bird species.

Survivorship may also vary greatly from one species to another. Most studies of avian survivorship have considered species one at a time, rather than combining them, and have presented survivorship analyses when 20 or more capture histories per species were available for analysis (Blake and Loiselle 2008). For migrant data, I had such large data sets only for two species in Certified Coffee, two different species in Forest Fragments, and one species in Natural Forest (no species in Technified Coffee or Open Areas). More data would be needed to analyze individual migrant species in any meaningful way. For the residents, apart from Clay-colored Thrush and Rufous-capped Warbler (analyzed separately), I had sufficient data sets for just two additional species in Natural Forest, none in Forest Fragments, none in Certified Coffee, two different species in Technified Coffee, and another two different species in Open Areas. Analyzing those additional species would not provide any cross-habitat comparisons.

Habitat use by dispersing forest birds

Dispersal is an important element in maintaining faunal distributions and genetic diversity, and in maintaining resiliency of a population against ecosystem change. Dispersal corridors should be seen as valuable ecosystem services for the conservation of genetic diversity. In the modern context of rapid climate change, and rampant land-use changes throughout the tropics, the capacity of a landscape to serve as a dispersal corridor for fauna is important to the ecological sustainability of regional economic development strategies, as well as biodiversity conservation strategies (Harvey et al. 2008).

The most important result of the study, with respect to dispersing forest birds, is the similar frequency of dispersers in coffee and forest habitats. Certified Coffee had a similar number of dispersers compared to both Natural Forest and Forest Fragments. Technified Coffee appeared to have fewer, but the frequency was not statistically different. Another important result was the discovery that Forest Fragments had large numbers of resident forest-specialist birds, which were essentially absent from the coffee plantations and the open areas. The small Forest Fragments not only seem to be an important part of the biological corridor, as stepping stones for dispersing birds, but also as refugia for populations of the forest specialists throughout the corridor and maintenance of metapopulations for these species. The capacity for gene flow in the corridor appears to be influenced much more by the presence of small forest fragments than by the presence of certified coffee plantations.

The counts of putative dispersing forest birds are conservative. Possibly many more individuals were dispersing but could not be distinguished from the resident populations of forest birds. More intensive monitoring of birds at some sites within the study area have found that approximately 30% of all birds are eventually recaptured, leaving 70% never recorded again (SalvaNATURA, unpublished data). Annual survivorship estimates are close to 58% for resident tropical birds (Blake & Loiselle 2008), thus I can assume that of the 70% of captured birds that are never recaptured, about 40% survive at least one year. Low capture probabilities may explain why some birds are never recaptured, but the capture probability over 12 site visits (such as those in the present study) is about 40%. Thus at least 16% of all birds captured can be presumed to be wanderers, moving through a monitoring site in search of a territory or more permanent home range. I classified 7.6% of the forest specialist birds captured as putative dispersers. The logic presented above suggests that only about 50% of the true dispersers were identified.

Although the results suggest that Certified Coffee plantations may have more dispersing forest birds than Technified Coffee plantations, the null hypothesis for this comparison could not be rejected. Furthermore, the Certified Coffee data included an outlier that may have inflated the results for that treatment due to some bias (perhaps an especially good location for dispersers, or perhaps a methodological bias such as opening nets earlier in the morning than at other sites). In sum, I conclude that certified and technified coffee plantations have similar capacities to attract dispersing forest birds.

Multivariate regression identified just two significant predictor variables for frequency of captures of putative dispersing forest birds: tree species richness and elevation. This result suggests that dispersing forest birds were not sensitive to shade canopy cover, overall tree abundance, or distance to paved roads.

Habitat use by migrants

One of the most important results of the study is the significantly higher levels of site fidelity by migrant birds in Certified Coffee and Forest Fragments, compared to Technified Coffee and Open Areas. Although the data suggested that Natural Forest may also have lower site fidelity, that result is possibly due to uneven distribution of the field work in the Natural Forest habitat, which reduced the opportunity for documenting site fidelity. Previous studies have demonstrated that migratory birds can be common in coffee plantations, but they have not demonstrated conclusively that shaded coffee is of higher quality or conservation value than other types of coffee or than other habitats (Komar 2006b). Higher site fidelity, however, clearly demonstrates a benefit for migratory birds, or at least that the birds perceive a benefit. In fact, it appears that Certified Coffee is as good for migrants as Forest Fragments, which in turn appeared to be slightly better than large patches of natural forest, at least for the set of species studied. Several migratory species that are more or less natural forest specialists, such as Wood Thrush (*Hylocichla mustelina*), Worm-eating Warbler (*Helmitheros vermivorum*), or Louisiana Waterthrush (*Parkesia motacilla*), were not evaluated during this study. Such species are not likely to fare better in coffee plantations, and were rare in the study sites (Appendix 4).

Supporting the conclusions of higher site-fidelity for migrant birds in Certified Coffee vs. Technified Coffee, I found significantly higher capture rates (=abundance) for wintering migrants in Certified Coffee (and both forest habitats), with respect to Technified Coffee and Open Areas. Previous mist-netting studies of migrants in coffee plantations of the Dominican Republic and Costa Rica had found similar abundance of migrants in shaded vs. sun coffee (Wunderle and Latta 1996, González 1999). The results may suggest that migrants prefer Certified Coffee to Technified Coffee, but an alternative explanation is that migrants were less detectable in Technified Coffee, which could generate similar results. The analysis of recaptures with Program MARK support this alternative, indicating much lower detectability in Technified Coffee, although causes of this lower detectability are not obvious (especially when a resident bird, the Clay-colored Thrush, presented higher detectability).

I had little data to evaluate use of different habitats as stopover feeding or resting areas by transient migrants, but the most abundant transient, the Canada Warbler, was caught more or as frequently in Certified Coffee than in any other habitat. This species, a boreal forest breeder, has been experiencing severe declines in recent years, and is considered Near-threatened by BirdLife International and IUCN (IUCN 2010).

A possible explanation for the higher site fidelity and abundance of migrants in Forest Fragments is better overall condition of the migrants in that habitat compared to other habitats, especially Natural Forest and Technified Coffee, which had significantly lower mean condition scores for migrants than Forest Fragments. Lower condition in Technified Coffee may be explained by farm management practices, especially the practice of using relatively high levels of insecticides and herbicides that may have both direct effects (intoxication) and indirect effects (reduced food resources) on birds. However, I was surprised to find similar condition scores in both coffee treatments, suggesting that Certified Coffee plantations also may be employing management practices detrimental to condition of migratory birds. Lower condition in Natural Forest may be explained by higher competition from native forest birds for food resources. I documented large numbers of forest-specialist birds occupying Natural Forest but not the more-disturbed coffee plantations, where generalist species, such as most migratory species, may be better adapted.

The overall results for the migrant guild may have been biased by preferences of the few species that dominated the migrant bird community, such as Swainson's Thrush and Wilson's Warbler. Although I have not evaluated wintering migrants for habitat preferences at the species level, an examination of the raw counts of captures (Appendix 4) suggests that six species may have a marked preference for Forest Fragments and Certified Coffee: Ruby-throated Hummingbird (*Archilochus colubris*), Swainson's Thrush, Yellow-bellied Flycatcher, Black-and-white Warbler (*Mniotilta varia*), Ovenbird, and Western Tanager (*Piranga ludoviciana*). In contrast, the species that appear to be more abundant in Technified Coffee and Open Areas, compared to more forested habitats, include only the Yellow Warbler (*Setophaga petechia*).

Habitat use by resident generalist birds

As was expected, the abundance of forest-generalist bird species (the majority of all bird species captured during the study) was similar among both coffee treatments and also Forest Fragments. But in Natural Forest, and especially in Open Areas, forest-generalist birds were significantly less abundant. In Open Areas, this can be explained by the overall lack of appropriate habitat, as by definition, forest-generalist birds live in forests and not necessarily also in open areas. (In a similar and opposite fashion, open-generalist bird species were most abundant in the Open Area treatment, less so in the coffee plantation treatments, and virtually absent in Natural Forest; summarized data in Appendix 4). In Natural Forest, most forest generalist species are resident but in lower densities than in Forest Fragments and coffee plantations. The pattern is the opposite for forest-specialist species, demonstrating that the generalists are better adapted to disturbed habitats, where they presumably out-compete the specialists for resources. In the Natural Forest, the specialists are better adapted and out-compete the generalists.

Why were just 24% of generalist forest birds in Certified Coffee in breeding condition, compared to approximately 34% in Technified Coffee and all other habitats? This result seems counterintuitive, if Certified Coffee is actually "bird-friendly". Nonetheless, such a result could be generated if resources for forest generalists were more stable in Certified Coffee year-round, such that forest generalist birds move into Certified Coffee habitats from any of the other four habitats during certain periods of the year, presumably to forage. The augmentation to the population would cause the relative size of the breeding population to appear to shrink. It could also be produced if dispersing generalist birds tend to select Certified Coffee habitats while undertaking dispersive movements in the non-breeding season. Another possibility is that shaded farms carry out more invasive pollarding during the breeding season that reduces the proportion of breeding individuals. These hypotheses require further testing before they can be evaluated.

The results for forest generalist birds may be biased by the dominance of just a few species in this guild. The Clay-colored Thrush and Rufous-capped Warblers far outnumber other species in the guild, and combined represent 39.5% of the birds of this guild captured during the study. The Clay-colored Thrush seems to be particularly successful in highly disturbed habitats, including Open Areas and Technified Coffee. Preferences by the other 48 species in the guild may be hidden by the preferences of the two dominant species.

13. General Conclusions and Recommendations

Were Rainforest Alliance Certified coffee farms bird-friendly? With respect to resident forest-specialist or forest-generalist bird species, Rainforest Alliance Certified coffee plantations in El Salvador were not more bird-friendly than randomly selected, non-certified technified coffee plantations. However, migratory birds in certified farms had higher apparent survivorship and longer site fidelity, but not better body condition, when compared to Technified Coffee farms. On the other hand, part of Rainforest Alliance certification is the long-term protection of small forest fragments on farm properties. Such fragments (all larger than 7 ha) were included as a treatment in the present study, although they were generally not located within Rainforest Alliance Certified farms (with one exception). They were found to be important for the conservation of forest-specialist bird species, many of which were captured at these sites but not within coffee production areas. Furthermore, the Forest Fragments presented significantly longer site-fidelity and better body condition for migratory birds when compared to Technified Coffee farms. Forest Fragments also had significantly more dispersing forest birds than Technified Coffee plantations or Open Areas. Small Forest Fragments also appeared to play an important role for migratory bird conservation. Migrants encountered their highest abundance, highest levels of site fidelity, and highest levels of body condition within the Forest Fragments.

Importance of coffee plantations for migratory birds

The study generated compelling evidence that Certified Coffee plantations have higher abundance of migratory birds, and higher site fidelity (an indicator of habitat quality), than either Technified Coffee plantations or open agricultural areas in El Salvador. In general, the indicators of habitat quality for migratory birds were similar for Certified Coffee and Forest Fragments, although body condition in Certified Coffee was similar to Technified Coffee and significantly lower than in Forest Fragments.

Recommendations for adaptive management

The results generated herein suggest two mechanisms for adjusting certification strategies for coffee plantations.

1. **Stressing the importance of conservation set-asides vs. eco-friendly agriculture**. In most measures studied, Certified Coffee farming was no more beneficial for birds than Technified Coffee farming. Yet Forest Fragments were significantly better than both coffee farming strategies for resident birds and for body condition of migratory birds. Agricultural certification programs could meet their goals for biodiversity conservation by permitting larger farming operations to create conservation set-asides, in which natural habitats are protected with no farming. Such a strategy would generate far greater biodiversity benefits than attempting to make the agronomy of the farming operations biodiversity-friendly. Farming, almost by definition, requires an extreme level of habitat disturbance, such that agroecosystems are virtually always of relatively poor quality for original biodiversity that requires the native forests or other habitats to

survive. Conservation set-asides may not be practical for small farming operations. The forest fragments included in the present study were larger than 7 ha and averaged 18.9 ha. Smaller fragments are likely to provide fewer biodiversity-conservation benefits. Therefore, while conservation set-asides are promising alternatives to eco-friendly agronomy, the latter is still recommended, especially for smaller farming operations that do not have the capacity to provide set-asides.

2. **Revising the criterion for tree species richness in certified farms**: The Rainforest Alliance Certified criteria (RAS 2009) suggest that a sustainable farm should have >12 native tree species per hectare. Such a threshold appears to be too low in El Salvador, where even open areas used for pasture or grain production presented 21 tree species per ha, and the technified coffee plantations presented 35 tree species per ha. Any kind of conservation program or sustainable agriculture certification in the study area should strive to improve on those figures. The certified coffee farms showed a total diversity improvement of 23 additional tree species (57 species per ha). I suggest that the criterion could be changed to "at least 10 native tree species per hectare more than a local baseline typical of highly disturbed areas".

Recommendations for follow-up field studies or analyses

The results presented also provide inputs for identifying new research needs applied to sustainable coffee.

1. **What size habitat fragment is useful as a conservation set-aside?** The present study demonstrates the value of small forest fragments for bird conservation in an agricultural landscape, even one dominated by agroforestry such as coffee cultivation. But all of our forest fragment study sites were located within fragments larger than 7 ha in size. Are smaller fragments also of importance to bird conservation? Is there a lower limit for size, below which fragments, or patches of trees, are not of value for bird conservation?

2. **Confirming preliminary results for migratory birds**. Some of the most intriguing results of the study are also only marginally significant. For example, results that indicate that migrant birds have higher levels of site fidelity in Certified Coffee and Forest Fragments than in the larger patches of Natural Forest and Technified Coffee. Previous published studies had been inconclusive about the value of shaded coffee for migratory birds (Komar 2006b). Additional data would be useful, especially for analyses of migrant capture probability, survivorship, and site fidelity.

3. **Testing for impacts of farm management practices on bird abundance.** The volume of data collected for birds in coffee plantations presents a rare opportunity to test for the effects of several coffee management practices on bird populations. But such tests will require gleaning farm records for the dates on which certain practices, such as applications of insecticides, harvest of coffee crops, or tree pruning, were carried out. The volume of bird captures over time can be compared to these activities, in search of signals in the data that indicate impacts of the activities on local bird abundance. Although these analyses were not planned, the existing bird capture data should be sufficient to detect impacts and document them with statistical tests. Such studies have not been published in the literature, and therefore could be of great value for understanding how biodiversity (birds in this case) interacts with coffee farming activities. Each test could be carried out independently for certified farms and technified farms, generating new light on the differences in biodiversity impacts for each type of farm.

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APPENDIX 1. Table of bird counts (response variables) for field sites.

Site	Forest specialists	Putative Forest Dispersers	Resident Generalists	Local Breeders	Site-faithful Resident Generalists	Migrants	Site-faithful Migrants	*Vireo flavoviridis*	*Cardellina canadensis*
BNCL	84	1	57	32	3	21	0	5	0
BNF1	18	0	22	0	0	35	0	13	0
BNF2	55	1	30	18	0	34	1	1	0
BNL1	13	1	73	20	10	21	3	1	0
BNPR	3	3	47	7	5	21	2	0	2
BNL2	5	0	73	13	4	20	1	0	0
BNBI	39	1	30	12	1	19	1	2	0
BNSB	71	3	45	23	3	54	1	7	1
BNCC	20	3	22	9	0	40	0	0	0
BNFM	55	1	41	10	3	24	0	8	0
PBSI	65	3	64	29	6	40	1	3	0
PBCA	6	3	73	10	3	22	1	6	0
PBTS	12	0	63	17	2	22	1	0	0
PBSU	7	0	38	7	1	13	1	7	2
PBBN	49	2	99	28	12	50	2	2	2
PBCO	11	0	70	9	6	86	9	2	0
PBJA	32	3	71	32	6	34	0	8	0
PBTU	9	0	77	19	4	45	0	0	2
PBFP	64	2	43	17	3	22	0	0	0
PBAT	13	2	64	29	9	30	2	3	1
CCMS	1	0	82	24	6	26	2	0	3
CCTC	2	2	37	10	0	44	2	0	0
CCSM	0	0	82	26	4	29	5	4	0
CCAN	1	1	55	14	3	20	0	1	1
CCNH	7	6	68	10	5	49	0	5	2

Site	Forest specialists	Putative Forest Dispersers	Resident Generalists	Local Breeders	Site-faithful Resident Generalists	Migrants	Site-faithful Migrants	*Vireo flavoviridis*	*Cardellina canadensis*
CCCH	0	0	96	22	12	42	5	0	3
CCGL	1	1	50	31	3	22	0	30	0
CCMA	2	2	56	1	0	41	0	0	3
CCAL	1	0	79	19	1	41	2	2	4
CCZA	1	1	66	5	1	27	0	2	3
CTMO	3	2	34	12	5	24	0	3	4
CTSH	1	1	36	6	2	19	1	3	1
CTGI	1	1	28	9	1	10	0	5	0
CTSB	1	1	53	12	4	12	0	3	0
CTCO	1	1	54	9	2	45	2	1	3
CTMC	0	0	94	37	18	9	0	4	0
CTES	0	0	77	39	5	28	5	22	0
CTSM	0	0	30	14	0	15	1	25	1
CTCA	0	0	74	22	2	17	0	12	4
CTRC	0	0	107	41	9	14	0	2	0
ZAGY	0	0	30	8	2	6	0	0	0
ZACS	0	0	8	14	0	13	2	0	0
ZAGG	0	0	33	5	0	6	0	0	0
ZAGA	0	0	39	5	0	17	0	0	0
ZAGL	0	0	5	5	0	10	1	0	0
ZAET	0	0	16	8	0	21	2	0	0
ZAGP	0	0	53	20	3	15	0	0	1
ZAGC	2	2	35	2	0	23	1	0	0
ZAPA	0	0	53	23	0	8	0	3	0
ZAPM	0	0	10	2	1	2	0	0	0

APPENDIX 2. Table of attributes (predictor variables) for field sites.

Site	Treatment	Altitude (m)	Shade cover (%)	Patch size (has)	Tree abundance	Tree richness	Distance to urban area (km)	Distance to highway (km)
BNCL	Natural Forest	1028	100.0	3132.91	63	29	7.50	7.90
BNF1	Natural Forest	800	43.9	3132.91	62	28	3.80	3.80
BNF2	Natural Forest	980	63.4	3132.91	93	30	5.40	5.40
BNL1	Natural Forest	998	94.8	522.64	46	29	1.30	0.40
BNPR	Natural Forest	710	75.3	226.97	53	24	0.50	1.70
BNL2	Natural Forest	600	99.9	522.64	37	20	2.00	0.90
BNBI	Natural Forest	700	92.2	3132.91	51	19	7.30	7.30
BNSB	Natural Forest	600	99.4	3132.91	83	29	8.20	8.20
BNCC	Natural Forest	1300	100.0	3132.91	83	37	4.40	5.00
BNFM	Natural Forest	600	54.0	3132.91	63	27	3.20	3.20
PBSI	Forest Fragments	1110	80.6	52.89	110	25	3.20	2.90
PBCA	Forest Fragments	485	95.6	24.82	70	28	1.80	0.40
PBTS	Forest Fragments	835	83.7	11.65	86	26	7.20	4.30
PBSU	Forest Fragments	455	62.2	37.63	72	21	1.40	3.90
PBBN	Forest Fragments	725	99.3	16.45	126	41	0.36	0.20
PBCO	Forest Fragments	630	68.9	7.25	60	16	1.70	2.25
PBJA	Forest Fragments	1050	84.9	7.24	110	24	3.10	0.45
PBTU	Forest Fragments	1255	61.5	10.65	59	18	5.30	2.80
PBFP	Forest Fragments	1125	84.9	9.42	96	23	3.80	1.80
PBAT	Forest Fragments	1240	89.6	11.07	72	14	0.90	0.10
CCMS	Certified Coffee	1215	38.0	38.85	75	16	4.50	6.00
CCTC	Certified Coffee	1055	33.1	67.90	88	28	5.80	4.10
CCSM	Certified Coffee	1075	35.6	22.05	76	17	6.80	3.20
CCAN	Certified Coffee	1255	51.5	30.10	70	6	1.40	1.30
CCNH	Certified Coffee	1150	46.9	62.90	35	19	6.70	3.50
CCCH	Certified Coffee	690	47.0	18.90	41	8	1.40	1.10

Site	Treatment	Altitude (m)	Shade cover (%)	Patch size (has)	Tree abundance	Tree richness	Distance to urban area (km)	Distance to highway (km)
CCGL	Certified Coffee	682	30.9	12.19	54	6	0.90	0.25
CCMA	Certified Coffee	753	43.6	85.19	82	16	4.80	5.20
CCAL	Certified Coffee	1075	34.6	20.65	74	7	4.50	1.70
CCZA	Certified Coffee	805	39.2	36.40	85	13	1.70	0.21
CTMO	Technified Coffee	1050	25.7	77.00	33	3	1.80	0.28
CTSH	Technified Coffee	1240	29.1	28.00	71	10	2.20	2.60
CTGI	Technified Coffee	1149	26.7	28.00	38	5	4.40	4.20
CTSB	Technified Coffee	1084	17.0	54.60	44	13	1.30	0.10
CTCO	Technified Coffee	1160	21.8	105.00	57	6	3.00	0.80
CTMC	Technified Coffee	776	26.9	9.10	28	5	4.20	0.77
CTES	Technified Coffee	630	12.8	4.90	36	5	0.00	0.17
CTSM	Technified Coffee	637	34.6	16.80	41	4	0.34	0.15
CTCA	Technified Coffee	598	39.0	16.10	44	10	1.50	1.50
CTRC	Technified Coffee	714	29.0	35.00	37	6	0.08	0.04
ZAGY	Open Areas	765	4.9	12.08	38	9	2.10	0.02
ZACS	Open Areas	730	25.4	8.64	17	4	0.75	1.20
ZAGG	Open Areas	745	9.1	2.02	17	5	1.50	2.85
ZAGA	Open Areas	958	5.0	0.57	24	5	4.30	1.35
ZAGL	Open Areas	607	3.0	2.70	20	3	3.20	0.35
ZAET	Open Areas	1140	4.3	0.98	16	1	4.60	5.50
ZAGP	Open Areas	682	32.0	5.60	32	3	3.00	5.00
ZAGC	Open Areas	990	2.6	13.30	19	4	1.65	0.55
ZAPA	Open Areas	1145	4.6	1.69	29	3	0.60	0.80
ZAPM	Open Areas	1105	8.2	1.80	37	6	0.30	0.60

APPENDIX 3. Table of tree morphotypes (species) and abundance in one hectare samples, by habitat treatment.

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
Acacia (*Acacia* sp.)	3	0	0	0	0
Acacia-Cedro	1	0	0	0	0
Aceituno (*Simarouba glauca*)	1	0	1	0	2
Achote montes (*Heliocarpus mexicanus*)	0	1	0	0	0
Aguacate (*Persea americana*)	4	0	6	2	4
Almendro de río (*Andira inermis*)	0	1	0	1	0
Almendro macho (*Styphnolobium sporadicum*?)	0	2	0	0	0
Aluminio (*Drypetes lateriflora*)	12	0	0	0	0
Amate (*Ficus* spp.)	6	8	1	0	3
Amate de río (*Ficus insipida*)	1	0	0	0	0
Anono (*Annona* sp.)	0	3	3	0	0
Anono colorado (*Annona reticulata*)	0	2	0	0	0
Arcabo (*Trichilia americana*)	8	0	0	0	0
Arito blanco (*Cestrum* sp.)	1	0	0	0	0
Arrayan (*Psidium friedrichsthalianum*)	0	0	3	0	0
Asta (*Saprantus palanga*)	1	1	0	0	0
Bálsamo (*Myroxylon balsamum* var. pereirae)	0	4	1	0	0
Cabo de hacha (*Luehea candida*)	0	0	0	1	0
Cacho de chivo (*Godmania aesculifolia*)	0	1	0	0	0
Cachulahuaca (*Ocotea botrantha*)	0	2	0	0	0
Cafecillo (*Faramea occidentalis*)	27	0	0	0	0
Caimito (*Chrysophyllum cainito*)	4	1	0	0	0
Calagüe (*Hampea stipitata*)	1	0	0	0	0
Caoba (*Swietenia humilis*)	4	8	10	0	0
Capulín (*Muntingia calabura*)	0	0	0	0	10

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
Capulín de monte (*Trema micrantha* var. *strigillosa*)	0	3	0	0	0
Capulín macho (*Trichospermum galeottii*)	1	8	2	1	0
Caraño (*Euphorbia schlenthendalianum*)	2	0	0	0	0
Carao (*Cassia grandis*)	1	4	0	0	0
Caulote (*Guazuma ulmifolia*)	7	9	0	1	0
Cedro (*Cedrela odorata*)	11	5	7	1	0
Ceiba (*Ceiba pentandra*)	1	4	1	0	1
Ceibillo (*Ceiba aesculifolia*)	0	6	0	0	0
Cerezo (*Ardisia compressa*)	5	0	0	0	0
Cerezo de Belice (*Syzygium cumini*)	0	0	1	0	0
Chaparrón (*Garcimia intermedia*)	13	0	0	0	0
Chaperno (*Lonchocarpus* sp.)	6	0	3	0	0
Chapulaltapa (*Lonchocarpus* sp.)	0	0	2	0	0
Chaquirrio (*Colubrina ferruginia*)	0	0	11	0	0
Chichicaste (*Urera* sp.)	6	0	0	0	0
Chichicaste rojo (*Urera eggersii*)	2	0	0	0	0
Chichicastón (*Wigandia urens*)	2	2	0	0	0
Chilamate (*Clusia guatemalensis*)	7	8	3	11	0
Chilindrón (*Cascabela ovata*)	6	5	0	0	0
Chirimuyo (*Annona cherimola*)	6	0	0	0	0
Chorrito (*Citharexylum donnellsmithii*)	0	1	0	0	0
Chulumuyo (*Rollinia mucosa*)	2	5	0	0	0
Cicahuite (*Lysiloma acapulcense*)	0	2	0	0	0
Cincho (*Lonchocarpus* sp.)	5	2	0	0	0
Ciprecillo (*Eugenia alfaroana*)	23	0	0	0	0
Ciprés (*Cupressus lusitánica*)	1	4	0	0	5
Cojón (*Stenmadennia pubescens*)	5	14	1	3	0
Cola de pava (*Cupania guatemalensis*)	17	6	0	1	0
Comuni	0	0	1	0	0

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
Conacaste (*Enterolobium cyclocarpum*)	4	4	0	0	5
Conacaste blanco (*Albizia niopoides*)	0	5	0	0	0
Copalchín (*Croton reflexifolius*)	8	5	0	0	6
Copinol (*Hymenaea courbaril*)	0	3	1	0	0
Cordoncillo (*Piper* sp.)	1	0	0	0	0
Cortez (*Tabebuia ochracea*)	0	3	4	5	0
Cortez blanco (*Tabebuia chrysantha*)	0	2	23	0	0
Cortez negro (*Tabebuia impetiginosa*)	3	1	0	0	0
Coyol (*Acrocomia mexicana*)	0	3	0	0	0
Crucito (*Randia* sp.)	5	21	0	0	0
Cuernavaca (*Solanum wrightii*)	0	0	6	2	0
Duraznillo (*Aphananthe monoica*)	5	0	0	0	0
Encino (*Quercus lancifolia*)	0	1	0	0	0
Escobo (*Eugenia* sp.)	12	0	0	0	0
Escobo blanco (*Maytenus chiapensis*)	1	0	0	0	0
Escobo negro (*Eugenia sasoana*)	1	0	0	0	0
Estoraque (*Styrax argenteus*)	17	1	0	0	0
Eucalipto (*Eucalyptus globulus*)	0	0	0	0	9
Flor de mayo (*Plummeria rubra*)	1	2	0	1	0
Funera (*Dalbergia salvanaturae*)	6	0	0	0	0
Gravileo (*Gravillea robusta*)	0	0	0	2	0
Guachipilin (*Diphysa americana*)	1	1	1	1	0
Guamito (*Inga punctata*)	0	5	12	1	0
Guarumo (*Cecropia peltata*)	5	13	0	0	3
Guayabo (*Psidium guajava*)	5	4	3	0	0
Guiliguishte (*Karwinskia calderonii*)	1	0	0	0	0
Hoja de queso (*Omphalea oleífera*)	0	9	0	0	0
Huesito (*Touhinia* sp.)	10	0	0	0	0
Huevo de mico (*Dichapetalum*	0	1	0	0	0

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
donnellsmithii)					
Hule (*Castilla elástica*)	0	2	1	0	0
Icaquio (*Eugenia jutiapensis*)	10	0	0	0	0
Inga (*Inga* sp.)	0	12	0	0	0
Irayol (*Genipa americana*)	2	0	0	0	0
Izcanal (*Acacia hindsii*)	1	13	0	0	0
Izote (*Yucca guatemalensis*)	0	0	0	3	0
Jiote (*Bursera simarouba*)	6	6	0	0	0
Jocote (*Spondias purpurea*)	0	0	0	0	7
Jocote corona (*Spondias purpurea* "var. corona")	0	0	5	0	0
Jocote del diablo (*Hyperbaena tonduzii*)	0	1	1	0	0
Jocote jobo (*Spondias mombin*)	3	15	0	0	0
Judio	5	0	0	0	0
Laurel (*Cordia alliodora*)	9	5	19	7	0
Laurel negro (*Cordia collococa*)	0	1	0	0	0
Lima (*Citrus* sp.)	0	0	1	0	0
Limon (*Citrus* sp.)	0	0	0	6	0
Limon mandarino (*Citrus nobilis* var. *deliciosa*)	2	0	3	0	0
Llama del bosque (*Spathodea campanulata*)	0	0	3	1	0
Madre cacao (*Gliricidia sepium*)	4	4	13	5	12
Mamey (*Mammea americana*)	0	0	1	0	0
Mango (*Mangifera indica*)	6	1	4	4	6
Mangollano (*Pithecellobium dulce*)	0	4	0	0	0
Mano de león (*Dendropanax arboreus*)	13	3	0	0	0
Manzana rosa (*Syzygium jambos*)	17	1	4	3	0
Manzanito (*Malvaviscus arboreus*)	4	0	0	0	0
Maquilishuat (*Tabebuia rosea*)	1	2	2	1	2
Marañón Japonés (*Syzygium malaccense*)	0	0	2	0	0
Marillo (*Calophyllum brasiliense* var. *rekoi*)	21	4	0	0	0
Masorchillo	0	7	0	0	0
Matapalo (*Ficus* sp.)	1	0	0	0	0
Matasanillo (*Peltostigma ptelioides*)	7	0	0	0	0

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
Memble (*Poeppigia procera*)	1	2	0	0	0
Mora (*Maclura tinctoria*)	6	0	0	0	0
Mora de tunco (*Solanum* sp.)	1	0	0	0	0
Morro (*Crescentia alata*)	0	0	0	1	0
Mulato (*Triplaris melaenodendrum*)	3	2	0	3	0
Mulo (*Licania retifolia*)	8	6	0	0	0
Mundani (*Acrocarpus fraxinifolius*)	0	0	3	2	0
Naranjillo (*Swartzia ochnacea*)	0	8	0	0	0
Naranjo (*Citrus sinensis*)	0	0	12	21	0
Naranjo lima (*Citrus* sp.)	0	0	1	2	0
Nispero (*Manilkara zapota*)	7	2	0	0	0
Nogal (*Juglans olanchana*)	0	0	6	0	0
Ojo de Cangrejo	3	0	1	0	0
Ojushte (*Brosimum alicastrum*)	32	20	0	0	0
Orejuelo Blanco (*Simbopetalum penduliflorum*)	1	0	0	0	0
Palguishte (*Acacia polyphylla*)	0	7	0	0	0
Palo de yegua (*Matayba glaberrima*)	1	0	0	0	0
Papaturro (*Coccoloba montana*)	0	3	0	0	0
Papaturro negro (*Coccoloba* sp.)	0	1	0	0	0
Papaya (*Carica papaya*)	0	0	2	0	0
Paraíso (*Melia azadirach*)	0	0	8	1	0
Pata de venado (*Bauhinia cookii*)	0	1	0	0	0
Peine de mico (*Apeiba tibourbu*)	1	3	0	0	0
Pepenance (*Ximenia americana*)	2	0	0	0	0
Pepeto (*Inga* sp.)	18	7	24	17	4
Pepeto blanco (*Inga thiboudiana*)	0	0	0	6	0
Pepeto de montaña (*Inga* sp.)	0	0	2	0	0
Pepeto de río (*Inga vera*)	0	1	15	22	0
Pepeto negro (*Inga laurina*)	2	3	9	22	0
Pepeto peludo (*Inga calderonii*)	2	10	54	44	0

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
Pie de cabra (*Bauhinia* sp.)	4	0	0	0	0
Pie de palomo (*Trichilia trifolia*)	0	1	0	0	0
Pimientillo (*Ocotea* sp.)	0	0	6	0	0
Pimiento negro (*Ocotea* sp.)	2	0	0	0	0
Pino (*Pinus* sp.)	0	2	0	0	10
Pito (*Erythrina berteroana*)	3	5	4	0	1
Plumajillo (*Albaradoa amorphoides*)	1	0	0	0	0
Pochote (*Zanthoxylum kellermanii*)	28	0	0	0	0
Polvo de queso (*Albizia adinocephala*)	4	0	0	0	0
Quebracho (*Lysiloma auritum*)	1	2	0	0	0
Quina (*Coutarea hexandra*)	5	2	0	0	0
Roble (*Quercus skinneri*)	5	38	0	0	0
Rompe caite (*Celtis iguanaea*)	1	0	0	0	0
Ron-ron (*Astronium graveolens*)	3	0	1	0	0
Salamo (*Calicophyllum candidissimum*)	0	1	0	0	0
San Andrés (*Tecoma stans*)	0	1	1	0	3
Sangre de perro (*Bocconia arborea*)	11	1	0	0	0
Sangre de toro (*Lonchocarpus salvadorensis*)	0	2	0	2	0
Sapuyulo (*Prunus axitliana*)	1	0	0	0	0
Semilla de pajuil	25	0	0	0	0
Shilo (*Pseudobombax ellipticum*)	0	1	0	0	0
Sincuya (*Annona purpurea*)	0	2	0	0	0
Soguilla (*Citharexylum* sp.)	2	0	0	0	0
Sombra de conejo	4	0	0	0	0
Sombra de mulo (*Casearia sylvestris*)	10	0	0	0	0
Sp 1	0	4	0	0	0
Sp 2	0	1	0	0	0
Sp 3	0	1	0	0	0
Sulfatillo (*Parkinsonia aculeata*)	6	0	0	0	0
Tambor (*Gyrocarpus americanus*)	0	4	0	0	0
Taray (*Eisenhardtia adenostylis*)	1	0	0	0	0

Tree morphotypes (by local common name)	Natural Forest	Forest Fragment	Certified Coffee	Technified Coffee	Open Area*
Tatascamite (*Perymenium grande* var. *grande*)	1	1	0	0	0
Teca (*Tectona grandis*)	0	0	1	0	1
Tecomasuche (*Cochlospermum vitifolium*)	1	4	0	0	0
Tempate (*Jatropha curcas*)	0	0	0	0	1
Tempisque (*Sideroxylum capiri* subsp. *tempisque*)	0	2	0	0	0
Tempisquillo (*Sideroxylum tepicense*)	3	0	0	0	0
Tigüilote (*Cordia dentata*)	0	18	0	0	1
Títere	0	1	0	0	0
Uña de gato (*Machaerium biovulatum*)	0	2	0	0	0
Volador (*Terminalia oblonga*)	3	10	2	0	0
Zapote (*Pouteria sapota*)	0	1	1	0	0
Zapotillo (*Couepia poliandra*)	2	0	0	0	0
Zarzo (*Acacia polyphylla*)	5	1	0	0	0
Zorra (*Samanea saman*)	0	3	0	0	0
Zorrillo (*Roupala glaberrima*)	12	1	1	0	0
Total density (trees ha^{-1})	**633**	**475**	**320**	**207**	**96**
Species richness	**110**	**105**	**57**	**35**	**21**

*Open areas included pastures, planted corn fields, and planted sugar cane fields. Many of the trees in open areas formed parts of live fence rows, and some trees were at the edges of forestry plantations (eucalyptus and pine).

APPENDIX 4. Raw counts of captured birds, by species and habitat, in the Sierra de Apaneca, El Salvador, study area.

Tax. Order	Scientific Name	English Name	Status[1]	Natural Forest[2]	Forest Fragment	Certified Coffee	Technified Coffee	Open Areas	Total[2]
25	*Dactylortyx thoracicus*	Singing Quail	Res-Gen	1	0	0	0	0	1
55	*Bubulcus ibis*	Cattle Egret	Res-Open	0	0	0	0	1	1
68	*Cathartes aura*	Turkey Vulture	Res-Open	0	0	0	1	0	1
82	*Accipiter striatus*	Sharp-shinned Hawk	Mig	0	1	1	0	0	2
93	*Buteo platypterus*	Broad-winged Hawk	Mig	0	0	1	0	0	1
94	*Buteo nitidus*	Gray Hawk	Res-Gen	1	0	0	0	0	1
99	*Buteo jamaicensis*	Red-tailed Hawk	Res-Spec	1	0	0	0	0	1
192	*Zenaida asiatica*	White-winged Dove	Res-Open	0	0	0	5	16	21
194	*Columbina inca*	Inca Dove	Res-Open	0	0	4	30	41	75
195	*Columbina passerina*	Common Ground-Dove	Res-Open	0	0	0	0	14	14
196	*Columbina minuta*	Plain-breasted Ground-Dove	Res-Open	0	0	0	0	2	2
197	*Columbina talpacoti*	Ruddy Ground-Dove	Res-Open	0	1	0	17	53	71
200	*Leptotila verreauxi*	White-tipped Dove	Res-Gen	17	18	10	18	8	71
201	*Geotrygon albifacies*	White-faced Quail-Dove	Res-Spec	0	1	0	0	0	1
202	*Geotrygon montana*	Ruddy Quail-Dove	Res-Gen	1	0	0	0	0	1
211	*Piaya cayana*	Squirrel Cuckoo	Res-Gen	0	1	2	0	0	3
219	*Crotophaga sulcirostris*	Groove-billed Ani	Res-Open	0	3	2	7	29	41
226	*Glaucidium brasilianum*	Ferruginous Pygmy-Owl	Res-Gen	1	2	6	6	3	18
236	*Caprimulgus carolinensis*	Chuck-will's-widow	Mig	0	1	0	0	0	1
243	*Chaetura vauxi*	Vaux's Swift	Res-Open	0	0	1	0	0	1
247	*Campylopterus rufus*	Rufous Sabrewing	Res-Gen	0	21	11	1	2	35
248	*Campylopterus hemileucurus*	Violet Sabrewing	Res-Gen	38	44	11	4	1	98
250	*Colibri thalassinus*	Green Violet-ear	Res-Open	6	0	0	0	0	6
251	*Anthracothorax prevostii*	Green-breasted Mango	Mig	0	0	1	0	2	3
252	*Abeillia abeillei*	Emerald-chinned Hummingbird	Res-Spec	0	2	0	0	0	2
253	*Chlorostilbon canivetii*	Canivet's Emerald	Res-Gen	8	7	6	3	3	27
254	*Hylocharis eliciae*	Blue-throated Goldentail	Res-Spec	8	21	3	1	2	35
258	*Amazilia beryllina*	Berylline Hummingbird	Res-Gen	49	69	58	14	26	216

Tax. Order	Scientific Name	English Name	Status[1]	Natural Forest[2]	Forest Fragment	Certified Coffee	Technified Coffee	Open Areas	Total[2]
260	*Amazilia rutila*	Cinnamon Hummingbird	Res-Gen	17	20	85	33	35	190
261	*Lampornis viridipallens*	Green-throated Mountain-gem	Res-Spec	0	0	1	0	0	1
265	*Heliomaster longirostris*	Long-billed Starthroat	Res-Gen	1	0	0	1	2	4
266	*Heliomaster constantii*	Plain-capped Starthroat	Res-Open	0	0	2	0	0	2
269	*Archilochus colubris*	Ruby-throated Hummingbird	Mig	1	19	28	9	9	67
274	*Trogon elegans*	Elegant Trogon	Res-Gen	6	7	1	0	0	14
278	*Hylomanes momotula*	Tody Motmot	Res-Spec	1	0	0	0	0	1
280	*Momotus momota*	Blue-crowned Motmot	Res-Gen	29	33	23	16	3	104
281	*Eumomota superciliosa*	Turquoise-browed Motmot	Res-Gen	5	5	19	21	6	56
285	*Chloroceryle americana*	Green Kingfisher	Res-Spec	2	3	0	0	0	5
288	*Aulacorhynchus prasinus*	Emerald Toucanet	Res-Spec	1	0	0	0	0	1
289	*Pteroglossus torquatus*	Collared Aracari	Res-Gen	1	1	0	0	0	2
292	*Melanerpes aurifrons*	Golden-fronted Woodpecker	Res-Gen	0	3	15	20	9	47
297	*Colaptes rubiginosus*	Golden-olive Woodpecker	Res-Gen	0	2	6	5	0	13
305	*Dendrocincla homochroa*	Ruddy Woodcreeper	Res-Spec	19	2	0	0	0	21
309	*Dendrocolaptes sanctithomae*	Northern Barred-Woodcreeper	Res-Spec	4	0	0	0	0	4
310	*Xiphorhynchus flavigaster*	Ivory-billed Woodcreeper	Res-Gen	30	11	2	2	0	45
312	*Lepidocolaptes souleyetii*	Streak-headed Woodcreeper	Res-Spec	3	4	0	0	0	7
314	*Thamnophilus doliatus*	Barred Antshrike	Res-Gen	0	2	0	0	0	2
315	*Grallaria guatimalensis*	Scaled Antpitta	Res-Spec	0	1	0	0	0	1
317	*Myiopagis viridicata*	Greenish Elaenia	Res-Spec	7	15	0	0	0	22
319	*Elaenia frantzii*	Mountain Elaenia	Res-Spec	0	0	1	0	0	1
320	*Mionectes oleagineus*	Ochre-bellied Flycatcher	Res-Gen	13	24	0	0	0	37
322	*Oncostoma cinereigulare*	Northern Bentbill	Res-Spec	11	6	0	0	0	17
324	*Rhynchocyclus brevirostris*	Eye-ringed Flatbill	Res-Spec	7	4	0	0	0	11
325	*Tolmomyias sulphurescens*	Yellow-olive Flycatcher	Res-Gen	21	19	3	3	1	47
332	*Contopus sordidulus*	Western Wood-Pewee	Mig	0	0	0	0	4	4
333	*Contopus virens*	Eastern Wood-Pewee	Mig	0	0	2	0	0	2
334	*Contopus sp. (cf. cinereus)*	Pewee sp. (cf. Tropical Pewee)	0	0	0	0	1	0	1
335	*Empidonax flaviventris*	Yellow-bellied Flycatcher	Mig	8	20	11	3	0	42
337	*Empidonax alnorum*	Alder Flycatcher	Mig	1	2	2	2	1	8

Tax. Order	Scientific Name	English Name	Status[1]	Natural Forest[2]	Forest Fragment	Certified Coffee	Technified Coffee	Open Areas	Total[2]
338	*Empidonax traillii*	Willow Flycatcher	Mig	0	2	5	2	3	12
340	*Empidonax minimus*	Least Flycatcher	Mig	5	8	54	25	25	117
342	*Empidonax flavescens*	Yellowish Flycatcher	Res-Spec	1	1	0	0	0	2
345	*Attila spadiceus*	Bright-rumped Attila	Res-Spec	2	0	0	0	0	2
346	*Myiarchus tuberculifer*	Dusky-capped Flycatcher	Res-Gen	3	9	10	3	0	25
349	*Myiarchus crinitus*	Great Crested Flycatcher	Mig	0	0	2	0	0	2
350	*Myiarchus tyrannulus*	Brown-crested Flycatcher	Mig	3	0	2	0	0	5
351	*Pitangus sulphuratus*	Great Kiskadee	Res-Open	0	0	1	2	6	9
352	*Megarynchus pitangua*	Boat-billed Flycatcher	Res-Gen	0	3	4	3	1	11
353	*Myiozetetes similis*	Social Flycatcher	Res-Open	0	1	0	0	0	1
354	*Myiodynastes luteiventris*	Sulphur-bellied Flycatcher	Mig	1	2	2	0	0	5
360	*Tityra semifasciata*	Masked Tityra	Res-Gen	0	1	1	1	0	3
361	*Pachyramphus aglaiae*	Rose-throated Becard	Res-Gen	0	10	15	4	3	32
362	*Chiroxiphia linearis*	Long-tailed Manakin	Res-Spec	127	55	0	1	0	183
366	*Vireo flavifrons*	Yellow-throated Vireo	Mig	0	1	0	0	0	1
368	*Vireo solitarius*	Blue-headed Vireo	Mig	4	0	7	3	0	14
369	*Vireo gilvus*	Warbling Vireo	Mig	9	8	7	7	2	33
371	*Vireo philadelphicus*	Philadelphia Vireo	Mig	1	0	0	0	0	1
372	*Vireo olivaceus*	Red-eyed Vireo	Mig	0	0	0	2	0	2
373	*Vireo flavoviridis*	Yellow-green Vireo	Mig	37	31	46	90	3	207
374	*Hylophilus decurtatus*	Lesser Greenlet	Res-Spec	7	3	0	0	0	10
376	*Cyclarhis gujanensis*	Rufous-browed Peppershrike	Res-Gen	3	8	2	0	0	13
378	*Calocitta formosa*	White-throated Magpie-Jay	Res-Gen	0	0	3	1	0	4
380	*Cyanocorax melanocyaneus*	Bushy-crested Jay	Res-Gen	6	0	2	6	0	14
390	*Stelgidopteryx serripennis*	Northern Rough-winged Swallow	Res-Open	0	1	0	0	0	1
394	*Hirundo rustica*	Barn Swallow	Mig	0	0	0	0	3	3
397	*Campylorhynchus rufinucha*	Rufous-naped Wren	Res-Gen	5	21	30	53	14	123
399	*Thryothorus maculipectus*	Spot-breasted Wren	Res-Gen	13	29	1	3	0	46
400	*Thryothorus rufalbus*	Rufous-and-white Wren	Res-Gen	29	47	0	0	0	76
401	*Thryothorus pleurostictus*	Banded Wren	Res-spec	5	9	0	0	0	14
402	*Thryothorus modestus*	Plain Wren	Res-Gen	1	5	4	0	4	14
403	*Troglodytes aedon*	House Wren	Res-Gen	0	5	10	1	6	22
407	*Ramphocaenus melanurus*	Long-billed Gnatwren	Res-Spec	0	1	0	0	0	1

Tax. Order	Scientific Name	English Name	Status[1]	Natural Forest[2]	Forest Fragment	Certified Coffee	Technified Coffee	Open Areas	Total[2]
409	*Polioptila albiloris*	White-lored Gnatcatcher	Res-Gen	0	3	0	0	0	3
411	*Myadestes occidentalis*	Brown-backed Solitaire	Res-Spec	0	2	0	0	0	2
413	*Catharus aurantiirostris*	Orange-billed Nightingale-Thrush	Res-Spec	8	40	2	0	0	50
416	*Catharus ustulatus*	Swainson's Thrush	Mig	136	155	45	9	1	346
418	*Hylocichla mustelina*	Wood Thrush	Mig	3	0	1	0	0	4
421	*Turdus grayi*	Clay-colored Thrush	Res-Gen	79	140	180	279	88	766
422	*Turdus assimilis*	White-throated Thrush	Res-Spec	9	15	2	0	0	26
423	*Seiurus aurocapilla*	Ovenbird	Mig	28	25	15	6	2	76
424	*Helmitheros vermivorum*	Worm-eating Warbler	Mig	12	8	0	0	0	20
425	*Parkesia motacilla*	Louisiana Waterthrush	Mig	3	4	1	0	0	8
426	*Parkesia noveboracensis*	Northern Waterthrush	Mig	1	1	0	2	0	4
427	*Vermivora cyanoptera*	Blue-winged Warbler	Mig	0	1	0	0	0	1
428	*Mniotilta varia*	Black-and-white Warbler	Mig	27	15	13	1	0	56
429	*Oreothlypis peregrina*	Tennessee Warbler	Mig	15	21	35	26	15	112
430	*Oreothlypis ruficapilla*	Nashville Warbler	Mig	0	0	1	0	0	1
431	*Geothlypis poliocephala*	Gray-crowned Yellowthroat	Res-Open	0	0	1	0	5	6
432	*Geothlypis tolmiei*	MacGillivray's Warbler	Mig	0	0	2	4	10	16
433	*Geothlypis philadelphia*	Mourning Warbler	Mig	1	0	5	4	0	10
434	*Geothlypis formosa*	Kentucky Warbler	Mig	0	8	1	1	0	10
435	*Setophaga citrina*	Hooded Warbler	Mig	1	1	2	0	0	4
436	*Setophaga ruticilla*	American Redstart	Mig	0	2	1	1	0	4
437	*Setophaga magnolia*	Magnolia Warbler	Mig	7	2	16	18	2	45
438	*Setophaga petechia*	Yellow Warbler	Mig	0	3	7	19	19	48
439	*Setophaga caerulescens*	Black-throated Blue Warbler	Mig	0	0	1	0	0	1
440	*Setophaga townsendi*	Townsend's Warbler	Mig	2	0	0	0	0	2
441	*Setophaga virens*	Black-throated Green Warbler	Mig	0	0	2	0	0	2
442	*Basileuterus lachrymosus*	Fan-tailed Warbler	Res-Spec	95	60	3	2	0	160
443	*Basileuterus rufifrons*	Rufous-capped Warbler	Res-Gen	89	112	90	68	7	366
444	*Basileuterus culicivorus*	Golden-crowned Warbler	Res-Spec	11	17	0	0	0	28
445	*Cardellina canadensis*	Canada Warbler	Mig	3	7	20	13	1	44
446	*Cardellina pusilla*	Wilson's Warbler	Mig	23	23	59	30	5	140
447	*Myioborus miniatus*	Slate-throated Redstart	Res-Spec	0	1	1	0	0	2

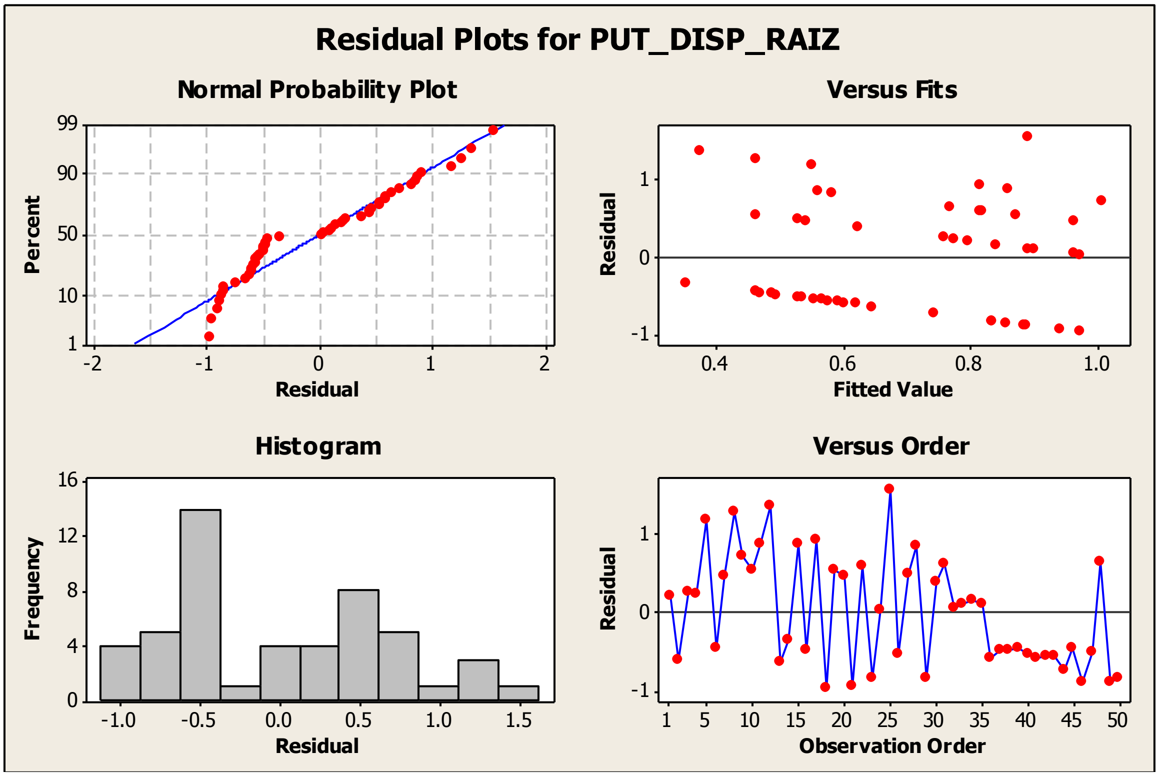
Tax. Order	Scientific Name	English Name	Status[1]	Natural Forest[2]	Forest Fragment	Certified Coffee	Technified Coffee	Open Areas	Total[2]
478	*Icteria virens*	Yellow-breasted Chat	Mig	1	6	16	9	7	39
480	*Habia rubica*	Red-crowned Ant-Tanager	Res-Spec	7	13	0	0	0	20
483	*Piranga rubra*	Summer Tanager	Mig	1	3	2	0	1	7
485	*Piranga ludoviciana*	Western Tanager	Mig	5	2	9	0	1	17
488	*Thraupis episcopus*	Blue-gray Tanager	Res-Gen	0	0	1	0	0	1
489	*Thraupis abbas*	Yellow-winged Tanager	Res-Gen	0	1	1	0	2	4
490	*Cyanerpes cyaneus*	Red-legged Honeycreeper	Res-Gen	2	0	2	0	1	5
491	*Volatinia jacarina*	Blue-black Grassquit	Res-Open	0	0	0	0	50	50
492	*Sporophila torqueola*	White-collared Seedeater	Res-Open	0	1	0	0	11	12
493	*Sporophila minuta*	Ruddy-breasted Seedeater	Res-Open	0	0	0	0	2	2
494	*Amaurospiza concolor*	Blue Seedeater	Res-Spec	4	0	0	0	0	4
500	*Melozone biarcuata*	Prevost’s Ground-Sparrow	Res-Gen	0	2	3	3	3	11
501	*Melozone leucotis*	White-eared Ground-Sparrow	Res-Spec	7	9	1	0	0	17
502	*Peucaea ruficauda*	Stripe-headed Sparrow	Res-Open	0	0	1	0	7	8
503	*Aimophila rufescens*	Rusty Sparrow	Res-Open	0	0	0	0	5	5
507	*Ammodramus savannarum*	Grasshopper Sparrow	Mig	0	0	0	0	1	1
510	*Saltator coerulescens*	Grayish Saltator	Res-Open	0	0	8	12	2	22
512	*Saltator atriceps*	Black-headed Saltator	Res-Gen	3	8	22	16	17	66
513	*Pheucticus ludovicianus*	Rose-breasted Grosbeak	Mig	0	3	3	0	1	7
514	*Cyanocompsa parellina*	Blue Bunting	Res-Spec	27	10	0	2	0	39
515	*Passerina caerulea*	Blue Grosbeak	Mig	0	0	4	6	4	14
516	*Passerina cyanea*	Indigo Bunting	Mig	3	5	1	5	15	29
517	*Passerina ciris*	Painted Bunting	Mig	6	41	15	15	7	84
520	*Sturnella magna*	Eastern Meadowlark	Res-Open	0	0	0	0	2	2
521	*Dives dives*	Melodious Blackbird	Res-Gen	0	0	2	4	0	6
522	*Quiscalus mexicanus*	Great-tailed Grackle	Res-Open	0	0	1	4	6	11
523	*Molothrus aeneus*	Bronzed Cowbird	Res-Gen	1	5	3	2	16	27
526	*Icterus maculialatus*	Bar-winged Oriole	Res-Gen	0	7	3	7	0	17
527	*Icterus spurius*	Orchard Oriole	Mig	0	0	1	0	0	1
529	*Icterus pustulatus*	Streak-backed Oriole	Res-Gen	4	19	52	37	11	123
531	*Icterus pectoralis*	Spot-breasted Oriole	Res-Gen	0	0	2	4	2	8
532	*Icterus gularis*	Altamira Oriole	Res-Gen	0	1	16	15	12	44
533	*Icterus galbula*	Baltimore Oriole	Mig	0	0	0	8	2	10
534	*Amblycercus holosericeus*	Yellow-billed Cacique	Res-Spec	0	0	1	0	0	1

Tax. Order	Scientific Name	English Name	Status[1]	Natural Forest[2]	Forest Fragment	Certified Coffee	Technified Coffee	Open Areas	Total[2]
537	*Euphonia affinis*	Scrub Euphonia	Res-Gen	0	0	0	2	0	2
538	*Euphonia hirundinacea*	Yellow-throated Euphonia	Res-Spec	13	11	1	1	0	26
543	*Spinus psaltria*	Lesser Goldfinch	Res-Open	0	0	0	0	7	7
		TOTALS		**1218**	**1472**	**1203**	**1065**	**693**	**5652**
		SPECIES RICHNESS		**85**	**101**	**99**	**75**	**72**	**162**

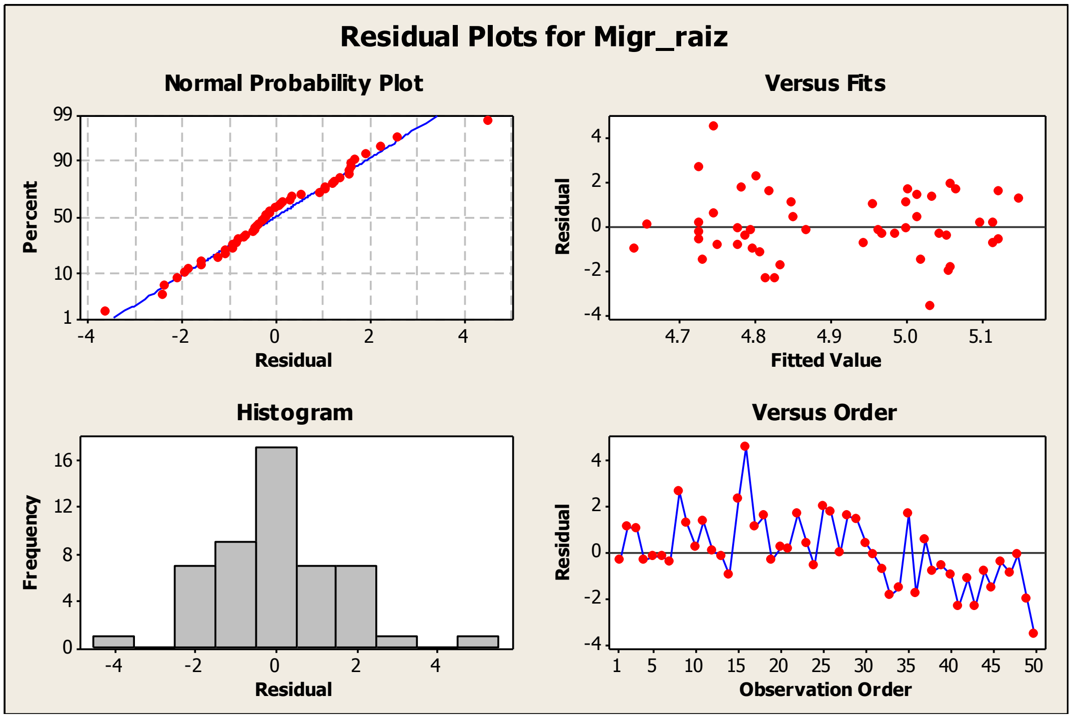
[1] Status abbreviations: Mig=Migratory; Res-Gen=Resident generalist; Res-Open=Resident open area specialist; Res-Spec=Resident forest specialist.

[2] Counts include all capture events, thus some recaptured individuals are counted more than once. The total count of recaptures was 394 (7% of all captures). Effort was 10,000 net hours per habitat, spread evenly among the 12 calendar months, except in the "natural forest" treatment, where effort was concentrated during the spring months.

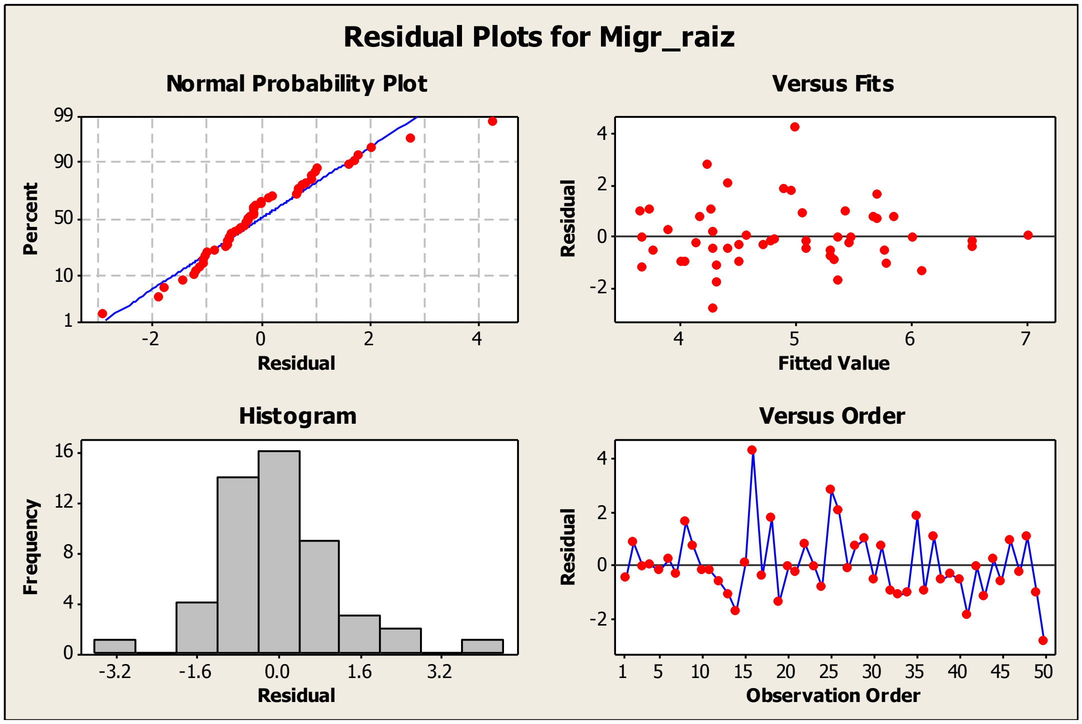
APPENDIX 5. Out-put graphs from Minitab, for examination of how well data fit test assumptions, for ANOVA tests and linear regression.



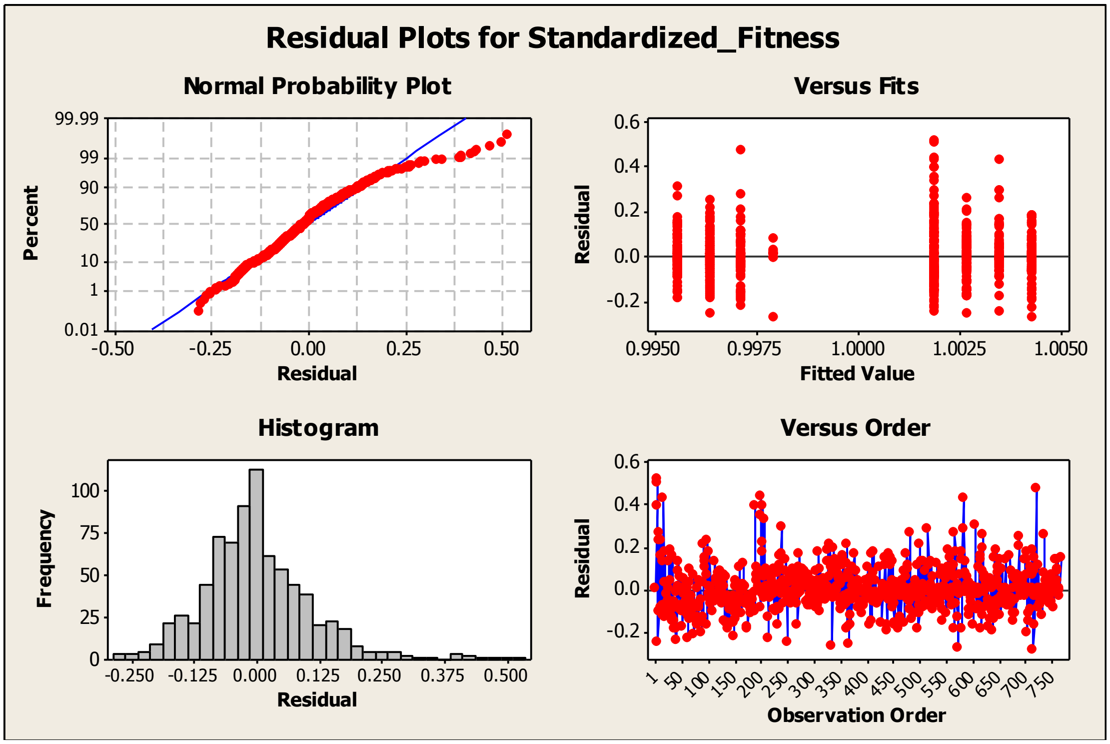
Transformed counts of putative dispersing forest birds.



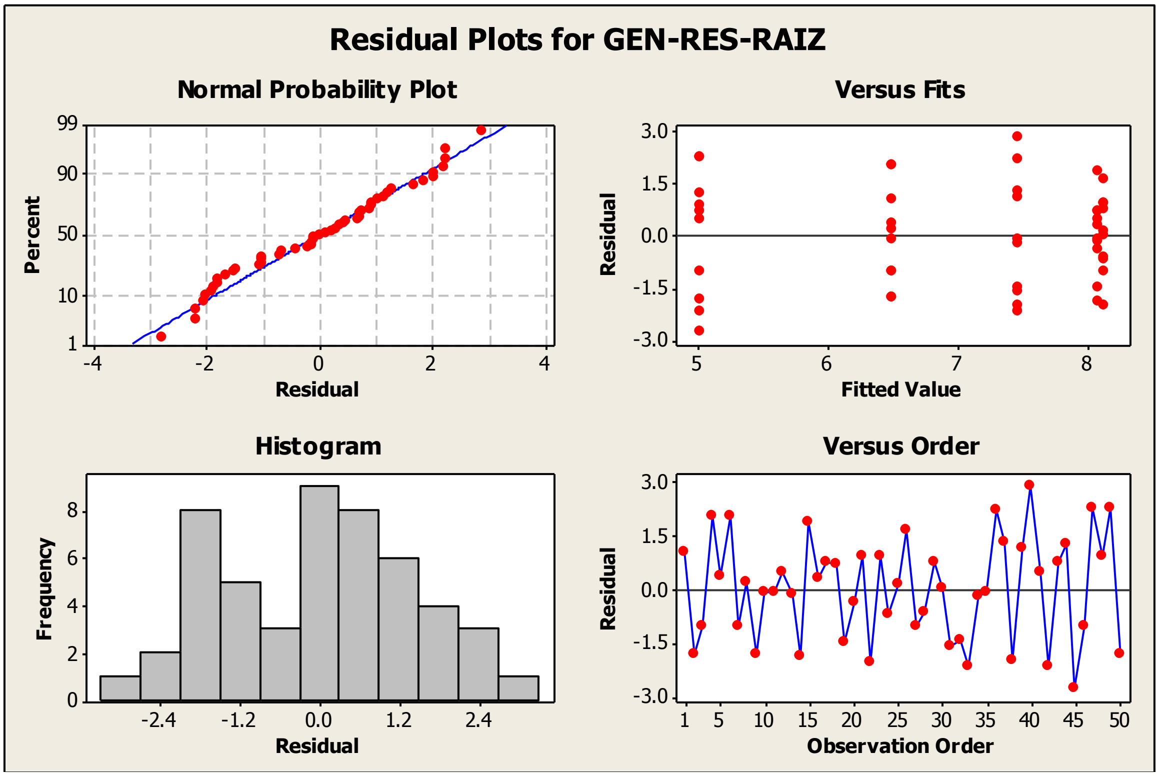
Transformed counts of wintering migratory birds fitted to elevation.



Transformed counts of wintering migrant birds fitted to tree abundance.



Standardized condition of wintering migrant birds, compared by month.



Transformed counts of resident generalist bird species, fitted to habitat.

APPENDIX 6. Design and protocol for a study of dispersing forest birds and migratory birds in El Salvador's Apaneca Biological Corridor (September 2007).

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INTRODUCTION

Shaded coffee plantations have often been proposed to be beneficial for birds, in particular forest bird species (Perfecto et al. 1996, Donald 2004). Fairly well documented hypotheses for how shaded coffee plantations benefit forest birds include: by providing additional foraging habitat (when close to forests; Terborgh and Weske 1969, Parrish and Petit 1996, Roberts et al. 2000); and by providing stopovers or wintering grounds for feeding and/or resting migrants (Wunderle and Latta 2000, Greenberg et al. 1997). Other hypotheses, involving potentially far more important benefits for conservation, remain poorly-documented (Komar 2006a). These include by providing additional quality breeding habitat (for disturbance-insensitive species), and by providing dispersal corridors for forest residents. The proposed study deals with the latter hypothesis, for which virtually no evidence has been published. Nonetheless, a radio-tracking study demonstrated that juvenile White-throated Robins (*Turdus assimilis*), born in Costa Rican pasture habitat, moved into neighboring forests to forage, and some of the birds were tracked moving first into shaded coffee plantations, presumably as they searched for adequate forest habitat (Cohen and Lindell 2004). Furthermore, a pilot study in the Apaneca corridor has suggested that forest specialist birds occasionally move through shaded coffee farms within the agricultural matrix of the corridor (Komar 2007).

The proposed study is designed to test the hypothesis that avian corridor users, in particular forest specialist bird species and migratory bird species, are more diverse and abundant in small forest fragments (conservation set-asides) and ecologically sustainable, shaded coffee plantations, such as those typically certified as Rainforest Alliance sustainable farms, than in less sustainable land uses such as technified coffee, basic grains, and or sugar cane production.

NOTES ON STUDY DESIGN

Analyses

Three response variables will be analyzed separately: (1) strict dispersers (forest specialists, essentially equivalent to locally threatened birds), (2) forest generalists that breed in the agricultural matrix, and (3) migratory visitors. The total number of individuals captured (excluding recaptures at the same site) within each group per samples of 1000 net-hours are the response variables. The species will be combined into the three groups based on concurrent observations of local breeding within the study sites, and for group 3, based on the seasonality of captures and observations. An additional response variable, nationally threatened birds, can be analyzed as well, and will likely be similar to the group of strict dispersers, since degree of natural habitat specialization is highly correlated to national threat status in El Salvador. Bird counts are typically poisson distributed (larger means, larger variances), so we will probably square root transform the counts of bird captures to achieve normally distributed residuals.

We will sample 5 levels of the main factor (habitat), using 10 mist-netting samples of 1000 net-hours each per habitat, spread evenly across 2 years (Table 1). Experimental units are sites consisting of 10 nets strung together and run for a total of 1000 net hours, spread across 12 visits over two years (one visit in each month). This design has been tested with a power analysis that suggested that the expected levels of difference between the test habitats (excluding the forest control, which is expected to be very different from all of the test habitats) for the rarer response variable (strict dispersers) should be statistically discernable (significant) in >82% of trials (Appendix).

To eliminate variability due to different altitudes, we will include altitude as a blocking factor, using two levels (5000 net hours in each altitude class within each habitat treatment; low altitude is 400 to 800 m, high is 900 to 1300 m). Higher altitude sites will not be studied because of probable interaction affects with altitude and distance to forest (because the ridge of the Sierra de Apaneca is generally forested, most potential study sites at higher elevations are close to forest sites; in general the affect of distance to forest will be controlled by selecting study sites >3 km from major forest sites).

Study site selection and site characterizations

There will be a total of 50 study sites, with a minimum distance between sampling (netting) sites of 1000 meters. We will use a cluster sampling method, randomly picking sampling blocks but placing clusters of net sites within each block (such as 2 net sites within each block). The blocks will range in size depending on the extent and distribution of each habitat type, and the size will depend on the ability to place at least 20 blocks over a map of each habitat in the landscape (for selecting 10 study sites). In general the affect of distance to forest will be controlled by selecting study sites >3 km from major forest sites. Within each site, netting efficiency will be maximized by placing nets in areas where birds are likely to not avoid them. This is justified because we need high capture rates to detect rare events. We will strive for consistency by picking the best netting sites within the constraints of the habitat and the randomized selection of study blocks.

There will be one control habitat type and four test habitat types. The minimum size criteria and habitat characterization for each type is presented below. We will describe the actual habitat treatments by documenting during the study the understory and overstory characteristics (vegetation profiles), including quantifying shade density and tree diversity in the canopy layer.

The control habitat is natural forest. The natural forest study sites will be located in patches at least 100 ha in size (no maximum size limit), with mean canopy height of 15 to 20 m, canopy cover of >80%, tree diversity >20 tree species per ha, and generally a mix of deciduous broadleaf trees and evergreen broadleaf trees. Elevations will range from 400 to 1300 m (with half the sites at lower elevations and half of the sites at higher elevations). Generally, the lower sites will be dry (semi-deciduous or deciduous) forest and the higher sites will be moist montane forest, which mimics the original forest types where the coffee plantations are located.

The first test habitat is shaded coffee plantation, selected as a proxy for Rainforest Alliance certified shade coffee. Some or all of these sites may in fact be certified by Rainforest Alliance as ecologically sustainable. These sites will have shade characteristics above the thresholds established in the Rainforest Alliance certification criteria; >40%

canopy cover (after tree pruning or pollarding) and diverse tree community in the canopy with at least 10 tree species providing shade to the coffee understory with mean densities >1 individual per ha). Sites must be located in patches of this habitat type with size > 4 ha (in practice, sites will be sought in larger patch sizes). There is no maximum patch size limit.

The second test habitat is technified coffee plantation, selected as a proxy for uncertified, non-shade coffee. These sites will have shade cover of <25%, lower average canopy height than the shaded coffee sites, <10 tree species in the canopy cover (probably an average of 3 tree species). Patch size will be > 4 ha (in practice, sites will be sought in larger patch sizes). There is no maximum patch size limit.

The third test habitat is small forest fragments. These sites represent conservation set asides that frequently exist in Rainforest Alliance certified (ecologically sustainable) coffee plantations. Some or all of the sites selected may in fact be located in Rainforest Alliance certified properties. The canopy cover in these sites will be >75% (similar to larger patches of natural forest), with tree species diversity >20 tree species with average densities of >1 species per ha. Canopy height will average >15 m. Minimum patch size should be 2 ha, but sites >4 ha will be sought. Maximum patch size is 50 ha, although smaller patches will be sought.

The fourth test habitat is open (low shade), non-permanent agriculture or pasture land. Shaded areas should be <10% (occasional shade trees are permissible, but not required). Dense understory (such as corn, sugarcane, or brush) is desirable for the placement of traps (nets). Minimum patch size is 2 ha, but sites >4 ha will be sought. There is no maximum patch size limit.

Adjusting for capture probabilities

Because of differences in capture probability among habitats due to differences in habitat structure and vegetation profiles, we will create a capture probability profile for each habitat for three guilds of bird species: understory, mid-story, and canopy species. The profile would be generated by determining the frequency of recaptures of resident individuals in each habitat. For example, if the 95% CI for recapture frequency over 2 years for mid-story birds in habitat A is 1.5–2.5 per 100 net hours, and in habitat B is 3.0–7.5 per net 100 net hours, then the correction factor for mid-story bird captures in habitat A is between 2–3 (we can use as a correction factor either the mean of 2.5 or the conservative lower limit of 2). All species's capture counts will be corrected for capture probability before carrying out comparisons between habitats..

As an alternate (experimental) measure of capture probability, we plan to use 400 fixed-radius (25 meter), 5-minute point counts of singing birds (aural counts, not visual counts), with 80 points per habitat (8 per study site) to estimate relative abundance for selected indicator species, conducted once during the breeding season. The relative abundance estimates will be converted to estimates of capture probabilities for species with similar vertical distributions within their natural habitats. Use of aural counts to correct for capture probability is highly experimental, as we are not aware of precedents in the scientific literature.

Statistical tests

Before combining species into their respective response groups, a chi-square test for homogeneity of variance will evaluate if any species should be removed from the groups or treated separately (some abundant species may be treated as response variables on their own, to evaluate their affects on the behavior of the species groups). The cells will include number of captures, with species as column headings and habitats as row headings.

For each site, we will run a GIS analysis for distance to natural forest, distance to major towns, distance to major roads, to evaluate the possible effects of these factors on the response variables (e.g., individuals of strict dispersers captured). Effects on response variables (bird capture frequency) of distance to natural forest, distance to major towns, and distance to major roads, will be evaluated with regression and correlation.

We will compare capture frequencies among treatments, corrected for relative capture probabilities that vary among habitats, using ANOVA general linear model (essentially, a randomized block design).

Table 1. Study site distribution for El Salvador for avian dispersal study. Two teams will work concurrently to collect the data, such that all field work can be completed in 600 or fewer field days.

Treatments	Potential localities	REPLICATES	Net-hours (1000/replicate)	Net-days (8.33 hours/net)	Days (10 nets per day)
Large patch natural forest LOW (Control)	El Imposible (3), Las Lajas Forest (2)	5	5000	600	60
Large patch natural forest MED (Control)	Concepción Miramar, Las Lajas Forest (2), El Imposible (2)	5	5000	600	60
Small patch natural forest LOW		5	5000	600	60
Small patch natural forest MED	Finca Nuevos Horizontes, Concepción Miramar	5	5000	600	60
Shaded coffee LOW	ATAISI Cooperative, Finca Porvenir (Izalco)	5	5000	600	60
Shaded coffee MEDIUM	Las Lajas Cooperative, Concepcion Miramar, Finca Nuevos Horizontes	5	5000	600	60
Technified coffee LOW		5	5000	600	60
Technified coffee MED	Finca El Aguila, Finca Santa Leticia	5	5000	600	60
GRAINS OR CANE LOW	ATAISI Cooperative	5	5000	600	60
GRAINS OR CANE MED	Las Lajas Cooperative	5	5000	600	60
TOTALS		50	50000	6000	600

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