

THE INFLUENCE OF ENVIRONMENTAL VARIABLES ON BIRD COMMUNITIES IN TROPICAL SEASONAL FORESTS, WESTERN THAILAND

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ABSTRACT

Tropical forest birds are highly vulnerable to habitat fragmentation, but little is known about the sensitivity of forest bird communities. The purpose of this project was to investigate the influence of forest landscape characteristics, vegetation characteristics, and human population on forest bird communities in the Western Forest Complex (WEFCOM), Thailand. Seventy-three study sites were classified according to size and distance from WEFCOM. The patches were grouped into one mainland (370,322 ha) and three forest patches i.e. large (768-6,847 ha), medium (223-768 ha) and small (1.6-223 ha). The distances in relation to the mainland were classified as near (7-7,250 m), middle (7,250-13,925 m) and far (13,925-25,503 m). In 2012-2013, a total of 290 point – count surveys were conducted and vegetation samplings collected at points in the mainland and in each of the three patches. In total, 139 bird species (2,770 individuals) were detected. The Linear mixed-effects model was used to examine how resident forest bird communities were affected by 12 environmental variables. The results showed that forest interior species and forest generalist species were affected by 3 variables: area patch sizes, distance from the mainland and tree basal area. The human population was the additional variable that affected forest interior species specifically. Determining the mechanisms of species loss by these variables presented an interesting picture. According to the results, conservation measures such as law enforcement, retaining and improving the quality of forest patches, and selecting and prioritizing patches as important shelter sites are needed for management. Monitoring some bird species as indicators of management success is also needed.

Keywords: Bird richness; bird abundance; forest fragmentation; forest birds

INTRODUCTION

The negative effects of deforestation are often further exacerbated by the fragmentation and configuration of the remaining forest, especially in tropical systems (Sodhi *et al.*, 2008; Bregman *et al.*, 2014). Clarifying the relative effects of deforestation and fragmentation (Fischer & Lindenmayer, 2007) is important for tropical forest management and biodiversity conservation (Gardner *et al.*, 2009). In tropical forests, birds are relatively common, diverse, and often sensitive to disturbance, making them useful as sentinels of tropical forest ecosystems (Powell *et al.*, 2015). In general, habitat destruction is highly detrimental to avian biodiversity in species-rich tropical and subtropical forests

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(Sodhi *et al.*, 2004; Gardner *et al.*, 2009). A recent review by Bregman *et al.* (2014) largely confirmed that birds in the tropics are at greater risk from habitat fragmentation compared to other forms of habitat disturbance across geographic regions. Therefore, it is very important to understand the mechanisms of the responses of species to fragmentation (Burkey & Reed, 2006). Although specialized tropical forest bird species appear to be highly vulnerable to habitat fragmentation (Newbold *et al.*, 2013), the degree of risk probably depends on a complex array of factors including their habitat preferences, their reproductive potential, and also how predators of their nests, fledglings and adults respond to fragmentation (Gates & Gysel, 1978).

Fragmentation-sensitive neo-tropical, and probably other tropical birds, are associated with some elements of vegetation structure not found in small (10 ha or 1 ha) forest fragments (Stratford & Stouffer, 1999). Few studies have been conducted in the tropics, especially tropical Asia (Wong *et al.*, 1999; Lambert & Collar, 2002; Lee *et al.*, 2005; Moradi *et al.*, 2009; Dayanada *et al.*, 2016). However, it is interesting to know how the relationship between vegetation structure and birds scales up to the larger landscapes (Powell *et al.*, 2015). Our basic understanding of the effects of forest disturbance on bird communities must be expanded, especially in Thailand's Western Forest Complex, the area of this study. The aim of this research was to study the effects of landscape and local environmental factors on resident bird communities in a tropical seasonal forest (dry dipterocarp and mixed deciduous forest). The hypothesis was that 1) forest patch size was the primary predictor of the richness and abundance of forest birds in any given patch, but 2) forest structure along with the level of human disturbance would also be important predictors.

MATERIALS AND METHODS

Study Area

We conducted this study in 2 areas in the vicinity of the Western Forest Complex (WEFCOM, 2004). The first study area is within the protected area of WEFCOM, (hereafter the mainland,) and while the latter encompass the surrounding area. The protected area included in this study composed of, which included the eastern parts of Huai Kha Khaeng Wildlife Sanctuary (Uthai Thani and Nakhon Sawan Provinces) and Mae Wong National Park (Nakhon Sawan Province), Thailand (~47P 52000E – 58000E, ~ 165000N-178000N) (Wildlife Conservation Office, 2006).

Land-use mapping was performed using Landsat-5 2006 TM images to locate the sampling sites. This mapping system is based on a hybrid classification method combining visual classification with supervised classification. A total of 602 patch sites were classified in the study area. All patches were then grouped based on size and distance from the mainland, using ArcMap 9.3. One mainland and 72 patch sites were randomly selected using a Microsoft Excel function. The existence and status of the selected patches were confirmed in the field. To locate the mainland sampling plots covering Huai Kha Khaeng Wildlife Sanctuary and Mae Wong National Park, the mainland was stratified into a northern, a middle, and a southern area, with 10 plots being established in each stratum (Figure 1).

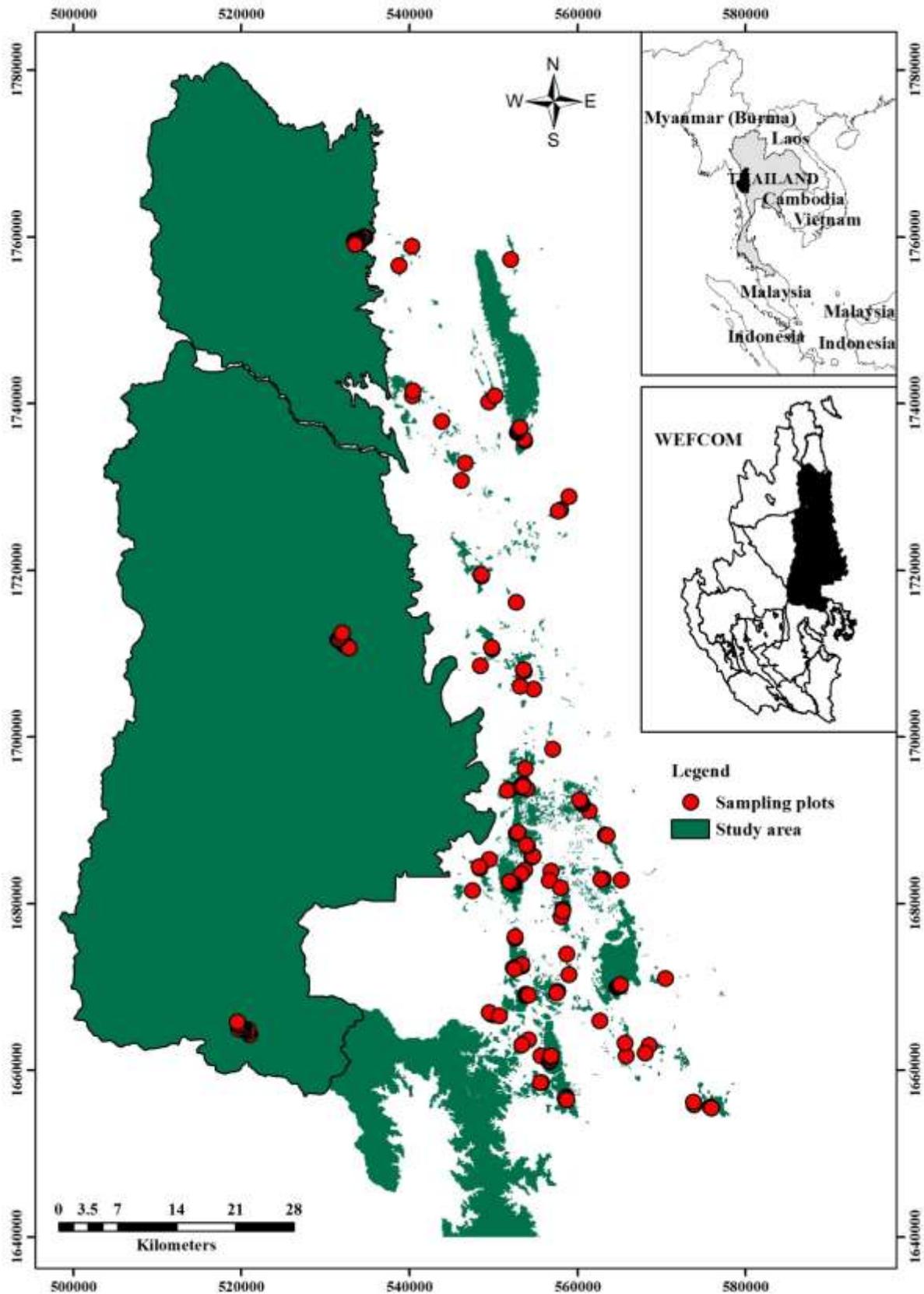


Figure 1 Sampling plot locations inside Huai Kha Khaeng Wildlife Sanctuary (A) and Mae Wong National Park (B) (yellow box), and 72 patches outside protected areas (red circles) (WEFCOM, 2004).

Data Collection and Analysis

Point Count Selection

The point counts, randomly located in the mainland and in each patch, were at least 300 m from the edge. In total, 145 point counts were set: 30 on the mainland; 115 in the patches. In order to avoid double counting, the distance between points in each patch was at least 250 m. Bird species, and the number of birds, were recorded by direct sighting and by listening to bird songs inside a 50 m radius, during a 10 minute period between 06:00–09:00. Bird species and their positions were observed using 8 × 42 binoculars. The Guide to the Birds of Thailand (Lekagul & Round, 1991) was used to aid identification. Data recording was started one to two minutes after reaching a counting point to allow birds to resume normal activity (Chang *et al.*, 2013). Birds flying overhead were not recorded. The coordinates of each point count were recorded using a GPS unit (UTM, WGS 84). In order to get enough sample sizes, regular bird sampling was conducted twice from May to October 2012 (first period) and from December 2012 to March 2013 (second period). To reduce the bias of time of day, the starting point was reversed for each period. Migrants were recorded but were not used in this analysis.

Table 1 Landscape and local vegetation variables used to assess the bird community inside and outside Huai Kha Khaeng Wildlife Sanctuary and Mae Wong National Park, Western Thailand.

Name of the variable*	Unit	Description
log (area) patch sizes	ha	Generated using ArcMap 9.3
(distance) to the mainland	m	Generated using ArcMap 9.3
(elevation)	msl	Generated using ArcMap 9.3
(human) population	N	Total number of people in near lest villages from sampling site.
(village)	m	Generated using ArcMap 9.3
(distance from village)	m	Generated using ArcMap 9.3
<i>Vegetation sampling design of five plots at a point count location.</i>		
number of (trees)	N	Total number of trees diameter > 4.5 cm in 10x10 plot
number of (seedlings)	N	Total number of tree seedling height <100 cm in 1x1 plot
number of (saplings)	N	Total number of trees diameter < 4.5 cm height > 100 cm in 4 x4 m plots
(ground cover)	%	Mean percentage of ground cover in 1x1 m plots
(canopy cover)	%	Mean percentage of crown cover in 10x10 plot
(tree basal area)	cm ²	Mean of tree basal area in 10x10 plot, average of cross-sectional area calculated from DBH size of all trees in sample sites.

Remark: * Short terms of independent variables are shown in parenthesis.

Landscape variables

At each sampling plots, we used six geographic variables assumed to have an influence on bird communities were generated: 1) area of patch size, 2) distance of points from the mainland, 3) elevation by using ArcMap 9.3, 4) total number of people in the nearest village as per Ministry of Interior data (Ministry of Interior, 2017), 5) total number of house in village as per Ministry of Interior data (Ministry of Interior, 2017) and 6) distance to nearest village (Table 1).

Plant community structure was studied within five 10m × 10m plots at each point count. One plot was located at the center of the point count, and the remaining four plots were set systematically at all four directions (N, E, S, W). All peripheral plots were located 50 m from the center (adapted from Marod & Kutintara, 2012). At the corner, within each 10 m×10 m plot, sub-quadrants of 4 m×4 m and 1m×1m were set. In each 10 m×10 m, 4 m×4 m, and 1 m×1 m plot, trees (diameter at breast height (DBH) ≥4.5 cm), saplings (DBH <4.5 cm and total height greater than 1.30 m), and seedlings were collected, respectively. In each 10 m×10 m plot, DBH of all trees > 4.5 cm were used to calculate tree basal area in sampling plots. Tree height and height of the lowest branch were recorded for each tree. Percentage of canopy cover was estimated using Spherical-Densimeter. In addition, in each 1 m×1 m sub-plot, the percentage of ground cover (including annual plants and vines) was estimated.

Data Analysis

Migrant birds were excluded from our analysis as they were likely to respond differently than resident birds (Hobson & Bayne, 2000). Resident bird data was categorized into forest birds and non-forest birds. The forest birds were separated further into two groups based on habitat selection: forest interior and forest generalists. Forest interior birds only inhabit the mainland, where, as stated by Lekagul & Round (1991) and Round *et al.* (2006), forest generalist birds are found in two habitats, namely the forest mainland and forest patches. Non-forest birds were removed from the analysis. Generalized linear mixed models (GLMM) were constructed in R program using package lme4 (Bolker *et al.*, 2011). GLMM provided a flexible approach for data analyses, offering a variety of uneven and repeated sampling units allowing for random effects. A poisson distribution was used to model richness and abundance. The models included 12 variables of fixed effects of landscape. These variables included potential human impacts (area patch size, distance from the mainland, forest total number of house in village, elevation, human population, distance from the village), and vegetation variables (numbers of trees, seedlings, and saplings, ground and crown covers, and tree basal area) (see Table 1). The survey periods were divided into first period (May-October) and second period (December – March), and the periods were chosen randomly.

The 12 variables were assessed prior to analysis using Spearman's rank correlation tests. If a variable of any pair was highly correlated ($r > 0.7$), it was discarded from the analysis because highly correlated variables, in the same regression, can cause serious errors (Khamcha, 2018). In this case, our findings showed only distance from the village strongly correlated with patch area ($r = 0.781$) and for this reason these two variables were not included in the same models. In order to evaluate the effects of the 12 measured variables on the richness and abundance of both

forest generalist and interior species, a set of generalized linear models, with binomial error distributions using logit link functions, was used. Model selection was based on Akaike's information criteria (Burnham & Anderson, 2002). The patch area sizes were transformed into logarithmic scale to compare values covering a large range of area data. Non-forest birds were discarded from analysis because forest birds seem to clearly evaluate the fragmentation effect. AICc tables were also generated using R-package AICc modelavg for model selection. Model averaging was used to estimate parameter values where the difference between models was less than two ($\Delta AICc < 2$). Null models were also used as baselines to assess the tested variables. The null models (intercept models) were designed to produce a pattern that would be expected in the absence of any effect of the tested variables (Gotelli & Graves, 1996). Statistical analyses were performed in R software (R Core Team, 2015). To evaluate bird richness and abundance in relation to the measured environmental variables, we created estimated regression lines and calculated estimated coefficients, standard errors, and 95% confidence intervals. The importance of environmental variables in the top performing models was assessed based on their respective Z-values, the associated probability of each variable's beta coefficient, and the 95% confidence interval of the beta estimates.

Table 2 Candidate models ($\Delta AICc < 2$) from generalized linear mixed models generated to evaluate environmental variables on forest interior species richness and abundance, based on variables included in models.

Independent variables	k	AICc	$\Delta AICc$	AICc Wt	Cum. Wt	LL
<i>Richness</i>						
distance +area+basal area +human	6	610.03	0.00	0.91	0.91	-298.87
distance +area +basal area	5	614.61	4.58	0.09	1.00	302.20-
human +area	4	642.69	32.65	0.00	1.00	-317.27
distance +area	4	649.54	39.50	0.00	1.00	-320.70
area +basal area	4	655.21	45.17	0.00	1.00	-323.53
human+ distance	4	672.32	62.28	0.00	1.00	-332.09
area	3	683.89	73.86	0.00	1.00	-338.90
distance + basal area	4	686.46	76.43	0.00	1.00	-339.16
distance	3	738.78	128.75	0.00	1.00	-366.35
human +basal area	4	806.94	196.90	0.00	1.00	-399.40
basal area	3	857.11	247.08	0.00	1.00	-425.51
human	3	938.38	328.35	0.00	1.00	-466.15
constant model (null)	2	1104.95	494.92	0.00	1.00	-550.46
<i>Abundance</i>						
distance + area + basal area + human	6	745.97	0.00	0.99	0.99	-366.84
distance + area + basal area	5	756.48	10.51	0.00	1.00	-373.14
human+ area	4	785.15	39.17	0.00	1.00	-388.50
distance + area	4	789.02	43.05	0.00	1.00	-390.44
area + basal area	4	794.43	48.46	0.00	1.00	-393.15

Table 2 (Continued).

Independent variables	k	AICc	Δ AICc	AICc Wt	Cum. Wt	LL
human + distance	3	830.15	84.18	0.00	1.00	-412.03
area	4	850.41	104.44	0.00	1.00	-421.13
distance + basal area	4	851.03	105.06	0.00	1.00	-421.44
distance	3	929.52	183.55	0.00	1.00	-461.72
human + basal area	4	101718	271.21	0.00	1.00	-504.52
basal area	3	1071.61	325.64	0.00	1.00	-532.77
human	3	1210.48	464.51	0.00	1.00	-602.20
Constant model (null)	2	1417.34	671.37	0.00	1.00	-706.65

Remark: Variables in model included: log area, distance from the mainland, tree basal area and human population. AICc Akike's information criterion values, Δ AICc the difference in AIC rank relative to the top model, wt the relative model weights, k the number of parameters in the model, LL log-likelihood.

Table 3 Estimate of coefficients of variables that suggest significant influence on forest interior species richness and abundance, standard errors (SE) and their 95% confidence intervals (CI) from model averaging.

	Estimated coefficient	Std. error	Z Value	Pr (> z)	Lower 95% CI	Upper 95% CI
<i>Richness</i>						
area	0.58481	0.09049	6.463	1.03e-10 ***	0.41053	0.7656
basal area	0.12403	0.04758	2.607	0.00914 **	0.0301	0.2167
distance	-0.71663	0.15760	-4.547	5.44e-06 ***	-1.0401	-0.4208
human	-0.32942	0.07092	-4.645	3.40e-06 ***	-0.46999	-0.19165
<i>Abundance</i>						
area	0.67659	0.08370	8.083	6.30e-16 ***	0.5153	0.8437
basal area	0.15005	0.04183	3.587	0.000334 ***	0.0676	0.2316
distance	-0.64331		-4.543	5.55e-06 ***	-0.9328	-0.3766
human	-0.28028	0.06259	-4.478	7.53e-06 ***	-0.40398	-0.1585

Remark: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

RESULTS

Forest Interior Bird Species Richness and Abundance

Twenty-seven models were generated to evaluate the influence of environmental variables on the richness and abundance of forest interior birds. The most supported model measuring these environmental influences contained four variables (i.e., log area, tree basal area, human population and distance from the mainland) and had an accumulative weight of 0.91 (Table 2-3). Estimates of

coefficients of the contained variables, and their 95% confidence intervals (CI), were calculated (Table 5). The model that most significantly illustrated the influence of environmental variables on forest interior species richness produced the following data: area ($z=6.463$, $\Pr(>|z|) = 1.3e-05$, estimates of coefficients = 0.58, 95% CI: (0.41) – (0.77)), distance from the mainland ($z = -4.547$, $\Pr(>|z|) = 5.44e-06$, estimates of coefficients = - 0.72, 95% CI: (-1.04) – (-0.42), human population ($z = - 4.645$, $\Pr(>|z|) = 3.40e-06$, estimates of coefficients = - 0.33, 95% CI: (-0.47) – (- 0.120), tree basal area ($z = 2.607$, $\Pr(>|z|) = 0.00914$, estimates of coefficients = 0.12, 95% CI: (0.03) – (0.21)). Results from the forest interior bird abundance model indicated that the same four variables influence abundance i.e. log area, tree basal area, human population and distance from mainland. The top model had an accumulative weight of 0.99. For this model, all four variables had significant coefficients: area ($z = 8.083$, $\Pr(>|z|) = 6.30e-16$, estimates of coefficients = 0.68, 95% CI: (0.52) – (0.84)), distance ($z = - 4.543$, $\Pr(>|z|) = 5.55e-06$, estimates of coefficients = - 0.64, 95% CI: (-0.933) – (-0.38)), human population ($z = -4.478$, $\Pr(>|z|) = 7.53e-06$, estimates of coefficients = - 0.28, 95% CI: (0.43) - (- 0.16), tree basal area ($z = 3.587$, $\Pr(>|z|) = 0.0044$, estimates of coefficients = 0.15, 95% CI: (0.07) – (0.23)) (Figures 2-3).

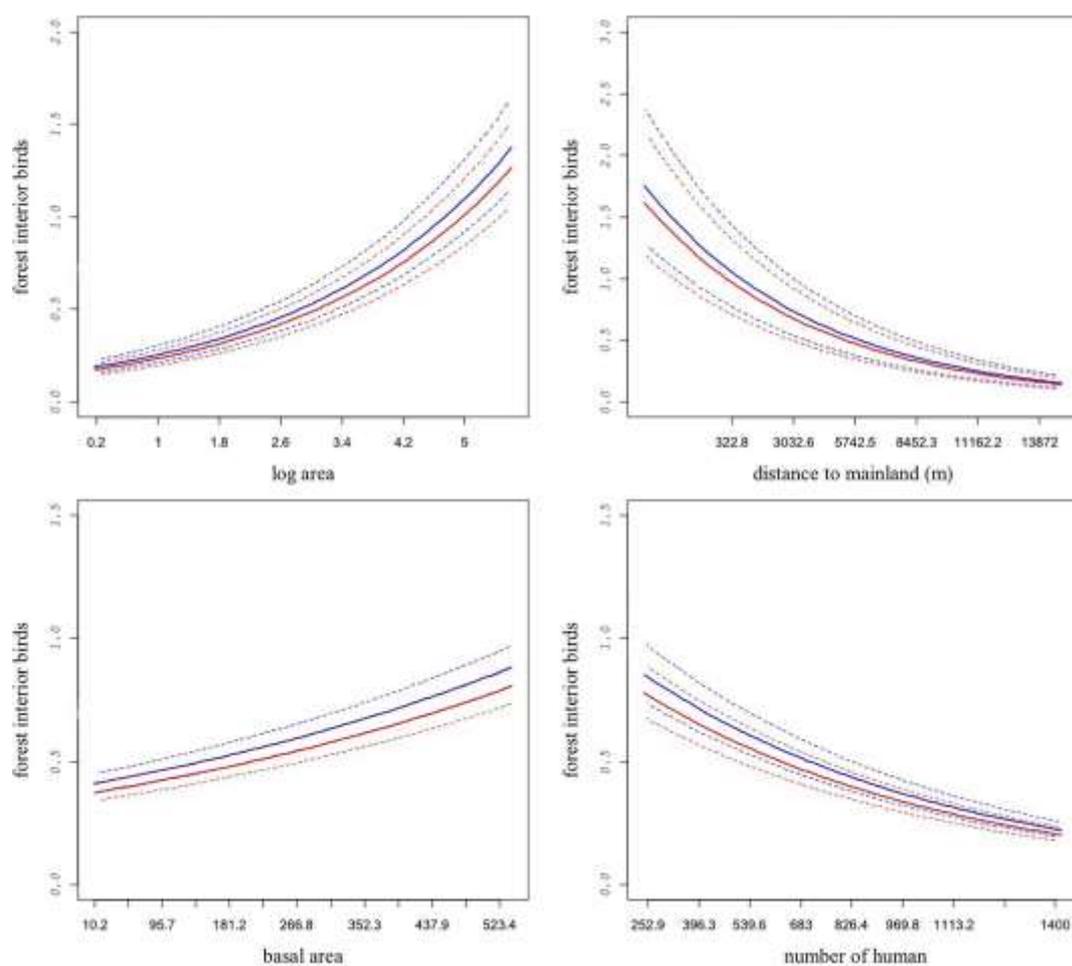


Figure 2 The estimated regression lines for forest interior bird richness and their response relative to environmental variables: log area, distance from mainland, basal area and human population. (blue lines = first survey period , red lines = second survey period, dot line = upper and lower 95 % CI).

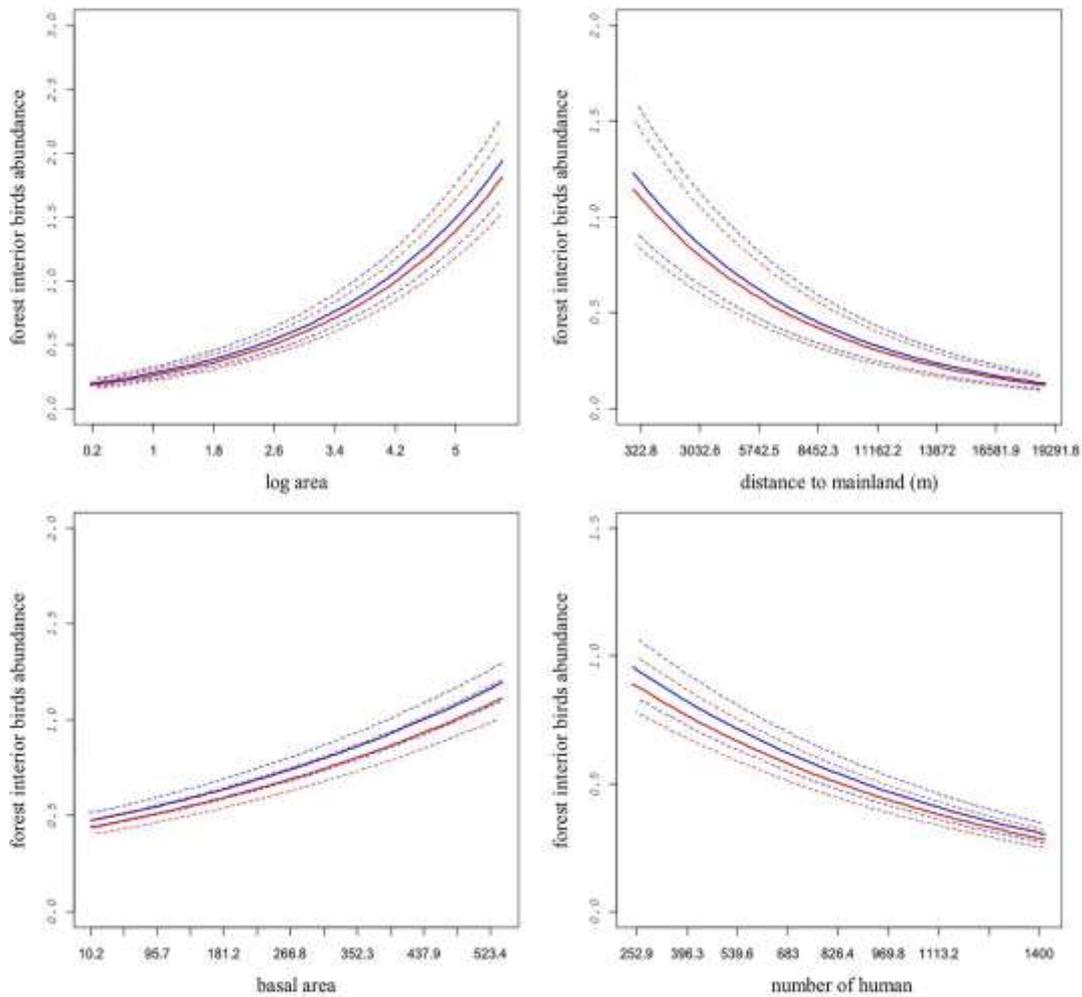


Figure 3 The estimated regression lines for forest interior bird abundance, and their responses, relative to environmental variables i.e. log area, distance to mainland, basal area and human population. (blue lines = first survey period , red lines = second survey period, dotted line = upper and lower 95 % CI).

Forest Generalist Bird Richness and Abundance

Twenty-two models were generated to evaluate the influence of environmental variables on richness and abundance of forest generalist birds. The most supported model included three variables (i.e., log area, distance from mainland, and tree basal area), with an accumulative weight of 0.87 (Table 6). Estimates of coefficients of the contained variables, and their 95% confidence intervals (CI), were calculated (Table 4-5). The model that most significantly illustrated the influence of environmental variables on forest generalist bird richness produced the following data: log area ($z = 2.843$, $\text{Pr}(>|z|) = 0.00447$, estimates of coefficients = 0.09, 95% CI: (0.03) – (0.14)), z -value was significant, but there was weak support for two variables distance ($z = 1.852$, $\text{Pr}(>|z|) = 0.06405$, estimates of coefficients = - 0.06, 95% CI: (-0.12) – (0.003)), basal area ($z = 0.971$, $\text{Pr}(>|z|) = 0.33132$, estimates of coefficients = - 0.08, 95% CI: (- 0.08) – (0.03)), z -value was not significant. For forest generalist bird abundance, the model with lowest Akaike in formation criteria included three variables

(i.e., log area, distance from the mainland, and basal area). Based on the criteria $\Delta AICc < 2$, only one top model was significant with an accumulative weight of 1.0 (Table 4-5). For the best model, the strongest deviation of z from zero was log area ($z = 5.811$, $Pr(>|z|) = <2e-16$, estimates of coefficients = 0.15, 95% CI: (0.10) – (0.20), z -value was significant but there was weak support for two variables (i.e., distance ($z = 1.252$, $Pr(>|z|) = 0.210$, estimates of coefficients = - 0.03, 95% CI: (0.07) – (0.005)) and basal area ($z = 0.758$, $Pr(>|z|) = 0.448$, estimates of coefficients = - 0.02, 95% CI: (-0.06) – (-0.02)), z -value was not significant (Figure 4-5).

Table 4 Candidate models ($\Delta AICc < 2$) from generalized linear mixed models to explain environmental variables on forest generalist species richness and abundance, based on variables included in models.

Independent variables	k	AICc	Delta_AICc	AICc Wt	Cum. Wt	LL
<i>Species richness</i>						
distance + area	4	1340.53	0.00	0.41	0.41	-666.19
distance + area + basal area	5	1341.64	1.11	0.24	0.65	-665.71
area	3	1341.74	1.22	0.22	0.87	-667.83
area + basal area	4	1343.65	3.12	0.09	0.96	-667.75
distance	3	1345.65	5.12	0.03	0.99	-669.78
distance + basal area	4	1347.70	7.18	0.01	1.00	-669.78
basal area	3	1357.84	17.31	0.00	1.00	-675.88
constant model (null)	2	1359.97	19.45	0.00	1.00	-677.97
<i>Abundance</i>						
area	3	1552.04	0.00	0.39	0.39	-772.98
distance+ area	4	1552.69	0.65	0.28	0.67	-772.28
area + basal area	4	1553.76	1.72	0.17	0.84	-772.81
distance + area + basal area	5	1553.81	1.77	0.16	1.00	-771.80
distance	3	1579.47	27.43	0.00	1.00	-786.70
distance + basal area	4	1580.72	28.67	0.00	1.00	-786.29
basal area	3	1594.98	42.94	0.00	1.00	-794.45
constant model (null)	2	1604.65	52.61	0.00	1.00	-800.30

Remark: Variables in model included: log area, distance from the mainland, tree basal area and human population. AICc Akaike's information criterion values, $\Delta AICc$ the difference in AIC rank relative to the top model, wt the relative model weights, k the number of parameters in the model, LL log-likelihood.

DISCUSSION

The generated models indicated that four of twelve measured environmental variables had a clear association with bird species richness and abundance. The four variables were log area of forest patch size, distance from the forest mainland, tree basal area and human population size near the

sample point. Of those four, the variables having the most effect were log area patch size and distance from the mainland. These findings are similar to those of other studies (Pattavibool & Dearden, 2002; Fahrig, 2003; Powell *et al.*, 2015). Chaiyes *et al.* (2009) states that bird assemblages are closely related to the volume of log area in forest patches. In that study, CCA analysis indicates that a patch size of 960 ha is the minimum area required to maintain a diversity of birds and that even the largest forest patches of 6,847 ha cannot provide suitable foraging microhabitats for insectivorous birds (e.g., Eared pitta (*Anthocincla phayrei*), Brown - cheeked fulvetta (*Alcippe poiocephala*), Velvet fronted nuthatch (*Sitta frontalis*), Banded broadbill (*Eurylai*). However, there was evidence of some tolerant species, such as frugivores and nectarivores, being present even in the small patches (e.g., Black-crested bulbul (*Pycnonotus flaviventris*), Black-headed bulbul (*Pycnonotus atriceps*) and Purple sunbird (*Cinnyris asiatica*)). It was explained that when fragmented patches become smaller, nectarivorous species and some resilient species of frugivorous birds, such as Bulbuls, increase in abundance according to Pattavibool & Dearden (2002). This is similar to what was observed in Singapore where nectarivorous birds tended to survive well on the support of only a small patch of forest area (Sodhi *et al.*, 2004). A study by Khumcha *et al.*, (2018) found that the nectarivore-insectivore birds, such as sunbirds, show a positive response to the forest edge. Nectarivore-insectivore birds depend greatly on nectar, which is likely more abundant closer to the forest edge where higher light levels are a suggested cause of understory shrubs and lianas producing more flowers (Laurance, 2004; Barber & Marquis, 2011).

Table 5 Estimates of coefficients of variables that suggest significant influence on forest generalist species richness and abundance, standard errors (SE) and their 95% confidence intervals (CI) from model averaging.

	Estimate coefficient	Std. error	Z Value	Pr(> z)	Lower 95% CI	Upper 95% CI
<i>Species richness</i>						
area	0.08573	0.03005	2.843	0.00447 **	0.0266	0.14483
distance	-0.05680	0.03055	1.852	0.06405	-0.1169	0.00332
basal area	-0.02787	0.02857	0.971	0.33132	-0.0841	0.02836
<i>Abundance</i>						
area	0.14837	0.02544	5.811	<2e-16 ***	0.0983	0.1984
distance	-0.03470	0.02760	1.252	0.210	-0.07454	0.0051
basal area	-0.01917	0.02519	0.758	0.448	-0.0556	0.0172

Remark: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Tree basal area also influences species richness and composition, especially forest interior birds, as shown in studies by Ferger *et al.* (2014) and Mammides *et al.* (2015). A higher complexity of vegetation structure is positively associated with the richness and abundance of most insectivorous birds, especially bark-gleaning, sallying, terrestrial, and understory insectivores. A complex vegetation structure probably provides more diverse arthropod resources and foraging habitats (Ferger *et al.*

2014). Seven species of bark-gleaning woodpecker were detected in the forest interior or mainland: Laced woodpecker (*Picus vittatus*), Common flameback (*Dinopium javanense*), Grey-capped woodpecker (*Dendrocopos canicapillus*), Bay woodpecker (*Blythipicus pyrrhotis*), Great slaty woodpecker (*Mulleripicus pulverulentus*), Black-headed woodpecker (*Picus erythropygius*) and White-browed piculet (*Sasia ochracea*). Only two species, Common flameback (*Dinopium javanense*) and Grey-capped woodpecker (*Dendrocopos canicapillus*), were found to still exist in the forest patches.

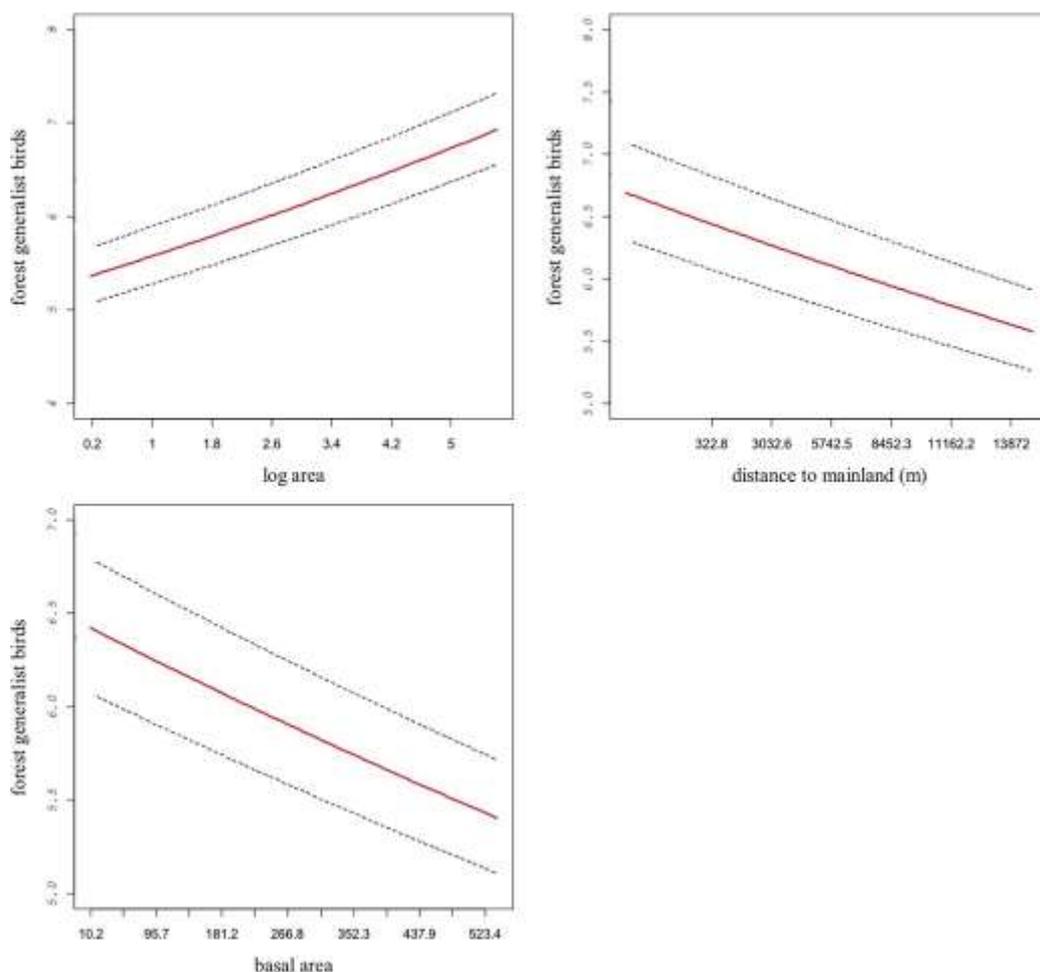


Figure 4 The estimated regression lines for forest generalist birds richness and their responses relative to environmental variables, log area, distance from the mainland and basal area. (red lines = first and second survey periods, dot line = upper and lower 95 % CI).

The effects of three of the variables in this study are clearly illustrated by frugivore birds with relatively larger body size (e.g., Tickell's brown hornbill (*Anorrhinus tickelli*), Great hornbill (*Buceros bicornis*), Oriental pied hornbill (*Anthracoceros albirostris*), Asian fairy bluebird (*Irena puella*), Green imperial pigeon (*Ducula aenea*), Mountain imperial pigeon (*Ducula badia*), Emerald dove (*Chalcophaps indica*), Green-eared barbet (*Megalaima faiostricta*), Great barbet (*Megalaima virens*) and Thick-billed green pigeon (*Treron curvirostra*). Although these species were found in abundance in the forest interior, their total disappearance from forest patches is perhaps due to the higher basal area and more potential food resources in the forest. Lindenmayer *et al.* (2012) suggest that the

higher basal area of a forest interior, combined with the density of large trees and the vegetation cover at canopy level, could provide greater fruit availability. Similarly, studies by Deikumah *et al.* (2014), Mammides *et al.* (2015) and Khamcha *et al.* (2018) show that fewer forest specialist and large-bodied frugivore species, such as hornbills and pigeons, are found at the forest edges.

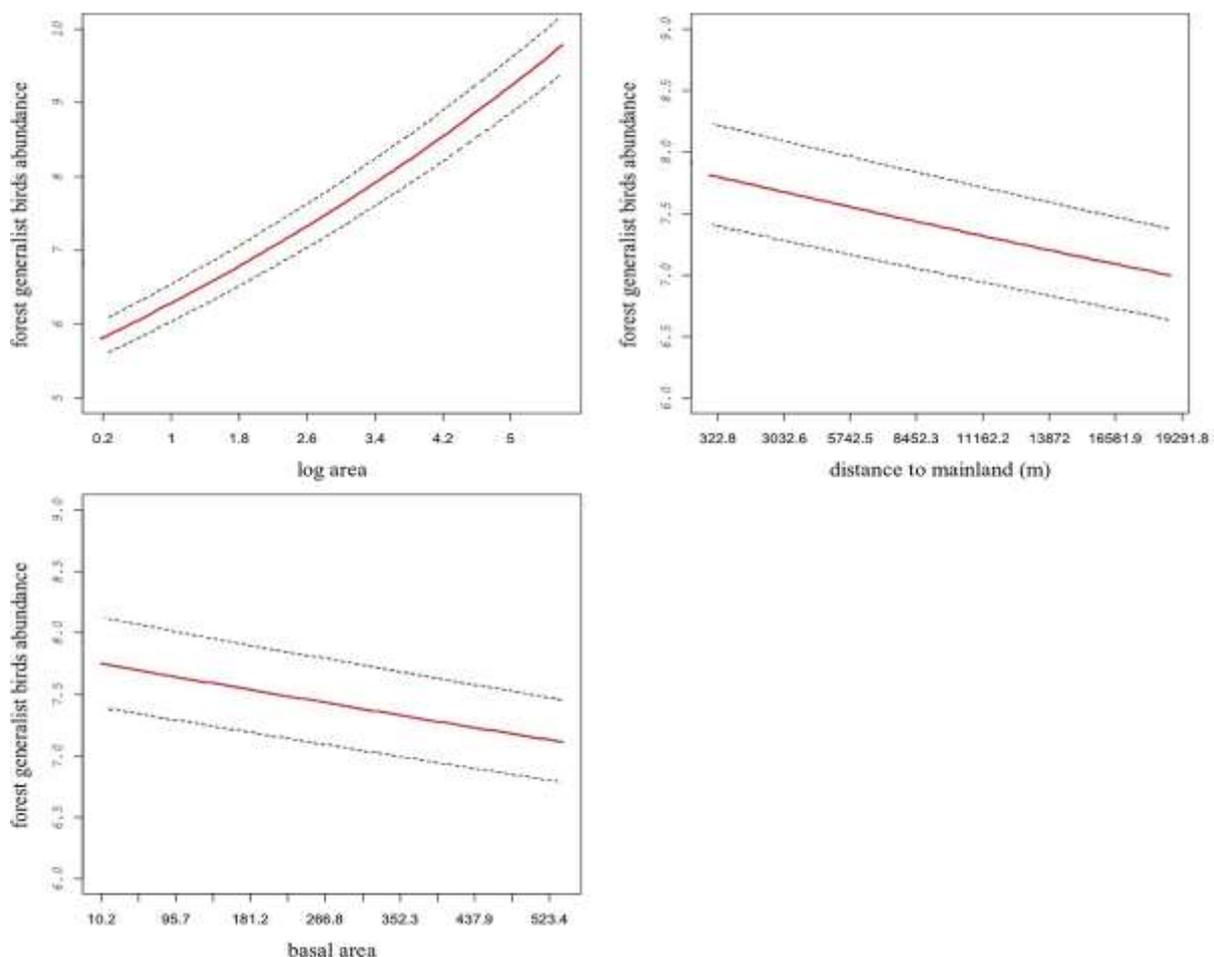


Figure 5 The estimated regression lines for forest generalist abundance and their responses relative to environmental variables log area, distance from the mainland and basal area. (red lines = first and second survey periods, dot line = upper and lower 95% CI).

Although basal area was clearly an important positive influence on forest interior birds, in contrast it was found to offer weak support for forest generalist birds and for this reason was not a significant influence on these species. While the vegetation structure of the forest interior was suitable more for forest birds requiring deciduous trees, some birds preferred forest patches with a high density of small trees. These patches, with higher vegetation cover near the ground but lower cover in the canopy, have lower total basal areas and lower density of larger trees (Dale *et al.*, 2000; Watson *et al.*, 2004). Many forest generalist bird species were found living in such low basal area forest patches, at longer distances from the mainland (e.g., Tickell's blue flycatcher (*Cyornis tickelli*), Lesser necklaced laughingthrush (*Garrulax monileger*), Green-billed malkoha (*Phaenicophaeus tristis*),

Black-hooded oriole (*Oriolus xanthornus*), Chestnut-headed bee-eater (*Merops leschenaultia*), Black-naped monarch (*Hypothymis azurea*), and White-rumped shama (*Copsychus malabaricus*). Human density leads to anthropogenic activities and to declining wildlife populations (Woodroffe, 2000; Parks & Harcourt, 2002; Sodhi *et al.*, 2010). Findings of the current study show that human population appears to negatively affect forest interior birds. This finding has been confirmed by other studies which show that biodiversity values (species richness and abundance) are substantially lower in degraded forests, when compared to primary forests (with little or no human disturbance) (Harvey *et al.*, 2006; Gibson *et al.*, 2011).

RECOMMENDATIONS

Results from this study could provide basic knowledge for the development of an appropriate landscape management plan for the conservation of forest patches and bird communities throughout the Western Forest Complex of Thailand. The preferred focus of the manager would be on the large forest patch sizes connected to the forest mainland. Establishing stepping-stone corridors between mainland and other patches is important also as these are very crucial habitats for forest birds. These forest patches near WEFCOM can be intensively managed under long term law protection as community forests, non-hunting areas, or forest parks. Rehabilitation of degraded forest areas, by reforestation, should be considered by the manager, in addition to the promotion of unmodified landscape mosaics. Also recommended is the maintaining of moderate patch sizes near the mainland, for frugivore and insectivore birds. This would require increasing shrub and ground cover in each area in order to increase food sources such as insects and some food plant species. Lastly, the manager should determine which species and life history traits are vulnerable to landscape changes (Newbold *et al.*, 2013; Powell *et al.*, 2015) and then use these species as target and indicator species, to monitor management success.

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REFERENCES

- Barber, N.A. & R.J. Marqui. 2011. Light environment and the impact of foliage quality on herbivorous insect attack and bird predation. *Oecologia* 166: 401–409.
- Bolker, B.A., M.E. Brook, C.J. Clark, S.W. Geange, J.R. Poulsen, M.H.H. Stevens & J.S. White. 2011. **GLMMs in Action: Gene-by-Environment Interaction in Total Fruit Production of Wild**

- Populations of *Arabidopsis thalina*.** Available Sources: [http://www.cell.com/cms/ attachment/601623 /4742453 /mmc2.pdf](http://www.cell.com/cms/attachment/601623/4742453/mmc2.pdf), November 2014, 2015.
- Bregman, T.P., C.H. Sekercioglu & J.A. Tobias. 2014. Global patterns and predictors of bird species responses to forest fragmentation: implications for ecosystem function and conservation. **Biological Conservation** 169: 372–383.
- Burkey, T.V. & D. H. Reed. 2006. The effects of habitat fragmentation on extinction risk: Mechanisms and synthesis. **Songklanakar Journal of Science and Technology** 28: 10–37.
- Burnham, K.P. & D.R. Anderson. 2002. **Model Selection and Multimodel Inference: A Practical Information-theoretic Approach.** Springer, New York.
- Chaiyes, A., P. Duengkae, A. Wongwai, D. Pratumthong, W. Insaun, C. Wachrinrat & S. Teejuntuk. 2009. Influences of patch sizes on bird assemblages around western forest complex of Thailand. **Thai Journal of forestry** 28(2): 1–12.
- Chang, X., R.C. Quan & L. Wang. 2013. Bird conservation in extremely small tropical rainforest patches in southwest China. **Biological Conservation** 158: 188–195.
- Dale S., K. Mork, R. Solvang & A. J. Plumptre. 2000. Edge effect on the understory bird community in a logged forest in Uganda. **Conservation Biology** 14: 265–76.
- Dayanada, S. K., E. Goodle, M. B. Lee, J. J. Liu, C. Mammides, R. C. Quan, R. Sreekar & M. Yasuda. 2016. Effects of forest fragmentation on nocturnal Asian birds: A case study from Xishuangbanna, China. **Zoological Research** 37: 151–8.
- Deikumah, J.P., C. Mcalpine & M. Maron. 2014. Biogeographical and taxonomic biases in Tropical forest fragmentation research. **Conservation Biology** 28(6): 1522–1531.
- Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. **Annual Review of Ecology and Systematics** 34: 487–515.
- Ferger S.W., M. Schleuning, A. Hermp, K.M. Howell & K. Böhning-Gaese. 2014. Food resources and vegetation structure mediate climatic effect on species richness of birds. **Global Ecology Biogeography** 23: 541–549.
- Fischer, J. & D.B. Lindenmayer. 2007. Landscape modification and habitat fragmentation: A synthesis. **Global Ecology and Biogeography** 16: 265–280.
- Gardner, T., J. Barlow, R. Chazdon, R. Ewers, C. Harvey, C. Peres & N.S. Sodhi. 2009. Prospects for tropical forest biodiversity in a human-modified world. **Ecology Letters** 12: 561–582.
- Gates, J.E. & L.W. Gysel. 1978. Avian nest dispersion and fledgling success in field-forest ecotones. **Ecology** 59: 871–883.
- Gibson, L., T.M. Lee, L.P. Koh, B.W. Brook, T.A. Gardner, J. Barlow, C.A. Peres, C.J. Bradshaw, W.F. Laurance, T.E. Lovejoy & N.S. Sodhi. 2011. Primary forest are irreplaceable for sustaining tropical biodiversity. **Nature** 478(7369): 378–382.
- Gotelli, N.J. & G.R. Graves. 1996. **Null Models in Ecology.** Smithsonian Institution Press, Washington DC.
- Harvey, C., A. Medina, D. Merlo Sánchez, S. Vilchez, B. Hernández, J. Sáenz, J.M. Maes, F. Casanoves & F.L. Sinclair. 2006. Patterns of animal diversity in different forms of tree cover in agricultural landscapes. **Ecological Applications** 16(5): 1986–1999.

- Hobson, K.A. & E. Bayne. 2000. Effects of forest fragmentation by agriculture on avian communities in the southern Boreal mixed woods of western Canada. **Wilson Bulletin** 112(3): 373–387.
- Khamcha, D., R.T. Corlett, L.A. Powell, T. Savini, A.J. Lynam & G.A. Gale. 2018. Road induced edge effects on a forest bird community in tropical Asia. **Avian Research** 9(20): 1–13.
- Lambert, F.R. & N.J. Collar. 2002. The future for Sundaic lowland forest birds: long-term effects of commercial logging and fragmentation. **Forktail** 18: 127–146.
- Laurance, S.G.W. 2004. Responses to understory rain forest birds to road edges in central Amazonia. **Ecology Application** 14(13): 44–57.
- Lee, T. M., M. C. Soh, N. Sodhi, L. P. Koh & S. L. H. Lim. 2005. Effects of habitat disturbance on mixed species bird flocks in a tropical sub-montane rainforest. **Biological Conservation** 122: 193–204.
- Lekagul, B. & P.D. Round. 1991. **A Guide to the Birds of Thailand**. Darnsutha Press, Bangkok.
- Lindenmayer, D.B., W.F. Laurance & J.F. Franklin. 2012. Global decline in large old trees. **Science** 338: 1035–1036.
- Mammides, C., M. Schieuning, K. Böhning-Gaese, G. Schaab, N. Farwing, C. Kadis & T. Coulson. 2015. The Indirect effects of habitat disturbance on the bird communities in a tropical African forest. **Biodiversity Conservation** 24: 2083–2107.
- Marod, D. & U. Kutintara. 2012. Biodiversity observation and monitoring in Thailand. Pp. 53-63. In **The Biodiversity Observation network in the Asia - Pacific region**. S. Nakano, T. Yahara & T. Nakashizuka (eds.). Ecological Research Monographs, Tokyo.
- Ministry of Interior. 2017. **Statistical Population of the Village Data**. Available Source: www.mahadthai.com/gis/people.htm, April 8, 2017.
- Moradi, H.V., M. Zakaria, A. Mohd & E. Yusof. 2009. Plant-frugivore networks are less specialized and more robust at forest-farmland edges than in the interior of a tropical forest. **Oikos** 121:1533–1566.
- Newbold, T., J.P. W. Scharlemann, S.H.M. Butchart, C.H. Sekercioglu, R. Alkemade, H. Booth & D.W. Purves. 2013. Ecological traits affect the response of tropical forest bird species to land - use intensity. **Biology Science** 280: 21–31.
- Parks, S. & A. Harcourt. 2002. Reserve size, local human density, and mammalian extinctions in US protected areas. **Conservation Biology** 16: 800–808.
- Pattanavibool, A. & P. Dearden. 2002. Fragmentation and wildlife in montane evergreen forests, northern Thailand. **Biological Conservation** 107: 155–164.
- Powell, L.L., J. Norbert, J. Cordeiro & A. Stratford. 2015. Ecology and conservation of avian insectivores of the rainforest understory: A pantropical perspective. **Biological Conservation** 188: 1–10
- R Development Core Team. 2015. **An Introduction to R**. Available Source: <http://cran.r-project.org/doc/manuals/R-intro.pdf>, September 28, 2015.
- Round, P.D., G.A. Gale & W.Y. Brockelman. 2006. A comparison of bird communities in mixed fruit orchards and natural forest at Khao Luang, southern Thailand. **Biological Conservation** 15: 2873–2891

- Sodhi, N.S., M. Castelletta, W.Z. Loh, B.P.Y.H. Lee & R. Subaraj. 2004. Tropical lowland rainforest birds on a highly urbanized island: monitoring, losses and lessons. In 4th International Symposium on Urban Wildlife Conservation. May 1–5, 1999, University of Arizona, USA.
- Sodhi, N. S., M. R. C. Posa, T.M. Lee & I.G. Warkentin. 2008. Effects of disturbance or loss of tropical rainforest on birds. **Auk** 125:511–519.
- Sodhi, N.S., L.P. Koh, R. Clements, T. C. Wanger, J.K. Hill, K.C. Hamer, Y. Clough, T. Tschardtke, M.R.C. Posa & T.M. Lee. 2010. Conserving Southeast Asian forest biodiversity in human-modified landscapes. **Biological Conservation** 143: 2375–2384.
- Stratford, J.A. & P.C. Stouffer. 1999. Local extinctions of terrestrial insectivorous birds in a fragmented landscape near Manaus, Brazil. **Conservation Biology** 13(6): 1416–1423.
- Watson J.E.M., R.J. Whittaker & T.P. Dawson. 2004. Habitat structure and proximity to forest edge affect the abundance and distribution of forest-dependent birds in tropical coastal forest of southern Madagascar. **Biological Conservation** 120: 311–327.
- WEFCOM. 2004. GIS Database and its applications for ecosystem management, the western forest complex. National Park, Wildlife and Plant Conservation Department, Bangkok.
- Wildlife Conservation Office. 2006. **Huay Kha Kheang Wildlife Sanctuary**. Available Source: http://park.dnp.go.th/visitor/nationalpark/show.php?PTA_CODE=1054, July 24, 2014
- Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. **Animal Conservation** 3: 165–173.
- Wong, T.C., N.S. Sodhi & I. M. Turner. 1999. Artificial nest and seed predation experiments in tropical lowland rainforest remnants of Singapore. **Biological Conservation** 85:97–104.