Research Note

The Value of Rehabilitating Logged Rainforest for Birds

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Abstract: *The recent advent of carbon crediting has led to a rapid rise in biosequestration projects that seek to remove carbon from the atmosphere through afforestation and forest rehabilitation. Such projects also present an important potential opportunity to reverse biodiversity losses resulting from deforestation and forest degradation, but the biodiversity benefits of different forms of biosequestration have not been considered adequately. We captured birds in mist nets to examine the effects of rehabilitation of logged forest on birds in Sabah, Borneo, and to test the hypothesis that rehabilitation restores avian assemblages within regenerating forest to a condition closer to that seen in unlogged forest. Species richness and diversity were similar in unlogged and rehabilitated forest, but significantly lower in naturally regenerating forest. Rehabilitation resulted in a relatively rapid recovery of populations of insectivores within logged forest, especially those species that forage by sallying, but had a marked adverse effect on frugivores and possibly reduced the overall abundance of birds within regenerating forest. In view of these results, we advocate increased management for heterogeneity within rehabilitated forests, but we strongly urge an increased role for forest rehabilitation in the design and implementation of a biodiversity-friendly carbon-offsetting market.*

Keywords: biodiversity banking, Borneo, clean development mechanism, feeding-foraging guild, rainforest, selective logging

El Valor de la Rehabilitación de un Bosque Tropical Lluvioso para Aves

Resumen: *El reciente arribo de créditos de carbono ha llevado a un rápido ascenso en los proyectos de biosecuestración que buscan remover carbono de la atmósfera mediante la aforestación y la rehabilitación de bosques. Tales proyectos también representan una oportunidad potencial para revertir las pérdidas de biodiversidad resultantes de la deforestación y la degradación de bosques, pero los beneficios para la biodiversidad de las diferentes formas de biosecuestración no se han considerado adecuadamente. Capturamos aves con redes de niebla para examinar los efectos de la rehabilitación de un bosque talado sobre aves en Sabah, Borneo, para probar la hipótesis de que la rehabilitación restaura los ensambles de aves en el bosque en regeneración hasta una condición cercana a la observada en un bosque no talado. La riqueza y diversidad de especies fue similar en el bosque no talado y el rehabilitado, pero fueron significativamente menores en un bosque en regeneración natural. La rehabilitación resultó en una recuperación relativamente rápida de las poblaciones de insectívoros en el bosque talado, especialmente las que forrajean al vuelo, pero tuvo un marcado efecto adverso sobre frugívoros y posiblemente redujo la abundancia total de aves en el bosque en regeneración. En vista de estos resultados, recomendamos mayor manejo para la heterogeneidad en los bosques rehabilitados, pero instamos firmemente a un mayor papel de la rehabilitación de bosques en el diseño e implementación de un mercado de compensación de carbono amistoso con la biodiversidad.*

Palabras Clave: banca de biodiversidad, bosque tropical lluvioso, Borneo, gremio de forrajeo-alimentación, mecanismo de desarrollo limpio, tala selectiva

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Introduction

There is much current interest in biosequestration projects that remove carbon from the atmosphere through afforestation and forest rehabilitation (Laurance 2007). Such projects also present an important potential opportunity to reverse biodiversity losses resulting from deforestation and forest degradation, but the biodiversity benefits of different forms of biosequestration have not been considered adequately (Bekessy & Wintle 2008). Afforestation is by far the commonest method of biosequestration; an estimated 7 million ha of land are planted annually (FAO 2005). Such schemes typically involve establishing short-rotation tree plantations in monoculture on abandoned land and have only limited sequestration value (Glenday 2006) and very limited benefits for biodiversity (Barlow et al. 2007). An alternative carbon sequestration mechanism involves rehabilitation of selectively logged forests (Kobayashi 2007), which are much more effective carbon sinks than plantations (Harmon et al. 1990). In such schemes, forest structure is modified by planting a variety of native tree saplings and by cutting climbers, which retard tree regeneration and growth (Putz et al. 2001). Timber concessions cover approximately 20% of all tropical forests (FAO 2005); thus, there is ample potential to expand rehabilitation planting of logged forests across the tropics. To our knowledge, however, no one has investigated previously the potential costs or benefits of rehabilitation planting for biodiversity. Such an assessment would be particularly timely in view of recent suggestions that carbon crediting and biodiversity banking, in which saleable credits are also available for projects that offer a biodiversity benefit, should be combined (Bekessy & Wintle 2008).

We considered the effect of rehabilitation planting of rainforest on the island of Borneo, which is a center of biodiversity and endemism, and has rates of timber extraction among the highest worldwide (>100 m3/ha in some cases; Sodhi et al. 2004). These forests are dominated numerically by large tree species of the family *Dipterocarpaceae* (Johns 1996), which are valuable timber species, and by 2010, all forest outside of conservation areas is likely to have been selectively logged at least once (Hamer et al. 2003).

One of the most important areas of lowland, dry dipterocarp forest remaining is the 1 million ha Yayasan Sabah (YS) logging concession (Lambert & Collar 2002) in Sabah, northeastern Borneo. Within the YS concession is one of the oldest and largest rehabilitation programs in the tropics: the Innoprise and Forest Absorbing CO_2 Emissions (FACE) Foundation Rainforest Rehabilitation Project (INFAPRO: Moura-Costa 1996). This area was selectively logged in 1988–1989 following a modified uniform system (Whitmore 1984) in which commercial stems >0.6 m diameter were removed with tractor and high-lead cable extraction, resulting in a timber harvest of approximately 80 m^3/ha. Since 1993 INFAPRO has rehabilitated over 11,000 ha of forest through a combination of enrichment planting (44 species, approximately 330 seedlings/ha) and liberation cutting to remove vines, bamboos, and noncommercial trees and shrubs (Moura-Costa 1996). The INFAPRO area is surrounded by selectively logged forest, which was harvested at the same time with the same logging techniques and is naturally regenerating, and is close to 45,200 ha of unlogged forest in the Danum Valley Conservation Area (DVCA) and Palum Tambun Watershed Reserve. The close proximity of these three forest types within a single continuous forest therefore provides a unique opportunity to investigate the effects of rehabilitation of logged rainforest on biodiversity.

We used birds as our focal taxon. Borneo has >420 species, of which over half are confined to lowland rainforests, including >50% of endemic species (Lambert & Collar 2002). We determined effects of rehabilitation by comparing avian assemblages among unlogged, naturally regenerating, and rehabilitated forest. We examined differences in species richness, diversity, and trophic guild structure. We tested the hypothesis that rehabilitation planting of logged forest restores these ecological and functional properties of avian assemblages to a condition closer to that seen in unlogged forest.

Methods

Fieldwork was conducted from June to October 2007 and May to September 2008 within DVCA and the Ulu Segama Forest Reserve, Borneo (4°58'N, 117°48'E). We established 36 transects across unlogged, naturally regenerating, and rehabilitated forest (12 replicated transects in each forest type). Transects within each habitat were ≥500 m apart, with 300 m to 9 km between transects in different habitats. Results of studies in tropical forests indicate data from mist nets separated by >200 m and are statistically independent (Whitman et al. 1998; Pearman 2002; Hill & Hamer 2004). In our study, only 13 of 2211 individuals (0.6%) were sampled on more than one transect. We are confident therefore that our transects were sufficiently far apart to ensure statistical independence of data.

Avifaunal Sampling

Each transect contained 15 mist nets (12 × 2.7 m; 25-mm mesh size) erected end-to-end in a straight line and opened from 06:00 to 12:00 for three consecutive days (9720 mist net hours total). We did not sample in rain or high winds. To prevent resampling of individuals, we marked each bird with an individually numbered metal leg ring. Mist netting took place during the drier period of the year, but transects were rotated among forest types to limit temporal effects.

Data Analyses

SPECIES RICHNESS AND DIVERSITY

We used sample-based rarefaction curves with 95% confidence intervals, constructed in EstimateS (version 8.0; University of Connecticut, Storrs, Connecticut), to compare patterns of species richness among forest types. Species richness is sensitive to sampling size, and even though sampling effort was standardized, sampling efficiency or total abundance of birds could have varied across sites. Hence, we standardized accumulation curves by the total number of individuals sampled in each type of forest. In addition, to estimate the likely species pool in each forest type, we used EstimateS to calculate the mean of the four commonly used abundance-based estimators (ACE, CHAO1, JACK1, and bootstrap).

We compared species diversity among habitats with Fisher's alpha, which incorporates species richness and evenness of species abundance into a single measure (Magurran 2004). For this analysis we examined pooled data for transects in each habitat with pairwise randomization tests based on 10,000 resamples of the species abundance data, following Solow (1993), and carried out in the program Species Diversity and Richness (PISCES Conservation, Oxford, United Kingdom).

Trophic Guild Structure

We assigned species to 15 foraging-dietary guilds on the basis of the type of food they consume and their foraging technique (Lambert 1992; D.P.E., personal observation). We also divided species into separate foraging guilds (arboreal, sallying, and undergrowth foragers, the latter including terrestrial foragers) and feeding guilds (frugivores, insectivores, predators, and generalists [i.e., diet includes two or more food sources]). We used generalized linear models (GLZs) with binomial errors and logit links to analyze differences among habitats in each of these three guild structures. This method controlled for differences in abundance among forest types by comparing the proportional contribution of each guild to the total species assemblage of each type of forest.

Results

Species Richness and Diversity

We recorded 2211 individuals of 91 bird species (list available from D.P.E.). Species richness was higher in both unlogged and rehabilitated forests than in naturally regenerating forest (Fig. 1). This pattern was confirmed by resampling the data with the four common abundance-based estimators of species richness (Table 1). In addition, unlogged and rehabilitated forests each had significantly higher species diversity (Fisher's index) than did naturally regenerating forest (Table 1; $\delta = 4.0, p = 0.02$ and $\delta = 4.9, p < 0.01$, respectively), and diversity did not differ significantly between unlogged and rehabilitated forests (Table 1; $\delta = 0.7, p = 0.7$).

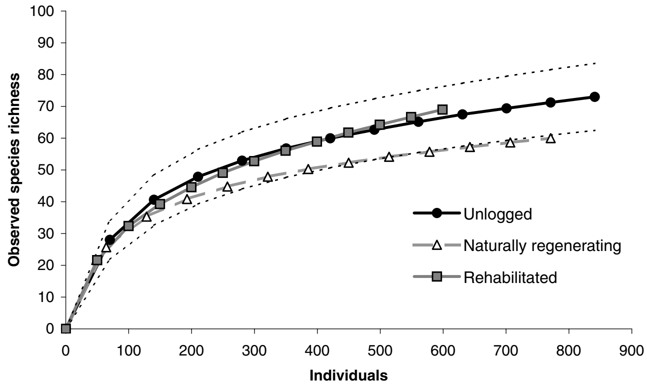

Figure 1. Observed species richness, constructed with sample-based rarefaction curves for the three forest types. The x-axis is scaled to show the number of individuals (dotted lines, 95% CIs for unlogged forest).

Feeding and Foraging Guilds

Of the 15 dietary-foraging guilds present, 7 differed significantly in relative abundance among the three types of forest, with frugivores consistently comprising a smaller proportion of birds sampled in rehabilitated forest (Table 2). Within the four dietary guilds, the proportion of frugivores was again significantly lower in rehabilitated forest (Fig. 2; $\chi^2 = 41.1, p < 0.0001$). In addition, the proportion of insectivores was significantly higher in rehabilitated and in unlogged forests than in naturally regenerating forests (Fig. 2; $\chi^2 = 12.8, p = 0.002$). In terms of foraging guilds, there was a significantly lower proportion of sallying birds in naturally regenerating forest compared with unlogged or rehabilitated forests (Fig. 2; $\chi^2 = 13.2, p = 0.001$).

Table 1. Summary of observed and estimated species richness, of Fisher's alpha index of diversity and of total abundance of individual birds in unlogged, naturally regenerating, and rehabilitated forests.*

Measure	*Unlogged*	*Naturally regenerating*	*Rehabilitated*
Observed species richness	73	60	69
Estimated species richness	87.9	71.7	104.5
Fisher's alpha index	19.2 (1.5)[a]	15.2 (1.3)[b]	20.1 (1.9)[a]
Total abundance	841	771	599

**Means (SE) are given. Different letters represent significant differences at the* p = *0.05 level in pairwise comparisons.*

Table 2. Mean percentage (SE) of individual birds belonging to each foraging-feeding guild within each habitat type.

Foraging-feeding guild	*Unlogged*	*Naturally regenerating*	*Rehabilitated*	p*
Arboreal gleaning insectivore	12.6 (1.8)	14.0 (1.5)	15.7 (2.4)	ns
Bark-searching insectivore	1.3 (0.7)	0.1 (0.1)	1.6 (0.7)	0.006
Sallying insectivore	8.2 (1.3)	5.2 (1.0)	7.5 (1.4)	0.029
Sallying gleaning insectivore	2.7 (0.8)	0.9 (0.4)	2.7 (1.0)	0.029
Undergrowth specialist insectivore	16.7 (2.2)	15.9 (1.4)	15.4 (1.7)	ns
Terrestrial insectivore	12.7 (1.9)	10.8 (1.3)	14.4 (1.8)	ns
Miscellaneous insectivore	1.9 (0.6)	2.3 (0.6)	2.2 (0.6)	ns
Arboreal frugivore	0.7 (0.4)	0.9 (0.6)	0.1 (0.1)	ns
Terrestrial frugivore	3.6 (1.1)	4.5 (0.9)	0.1 (0.1)	<0.001
Arboreal gleaning insectivore/frugivore	16.2 (2.1)	15.5 (1.7)	12.3 (2.0)	0.022
Terrestrial insectivore/frugivore	1.4 (0.7)	0.7 (0.3)	0.4 (0.2)	ns
Nectarivore/insectarivore/frugivore	12.8 (2.4)	19.8 (2.7)	19.4 (2.3)	ns
Nectarivore/insectivore	9.2 (1.2)	8.8 (0.9)	7.4 (1.2)	<0.001
Piscivore	–	0.5 (0.3)	0.4 (0.3)	0.035
Raptor	0.1 (0.1)	0.1 (0.1)	0.3 (0.3)	ns

**Calculated with generalized linear models with binomial error and a logit link.*

Discussion

Species richness and diversity of birds was significantly lower in naturally regenerating logged forest than in unlogged forest (Fig. 1, Table 1), which contrasts with results from several studies that did not find any difference in species richness after controlling for sampling effort (e.g., Marsden 1998; Cleary et al. 2005), including two

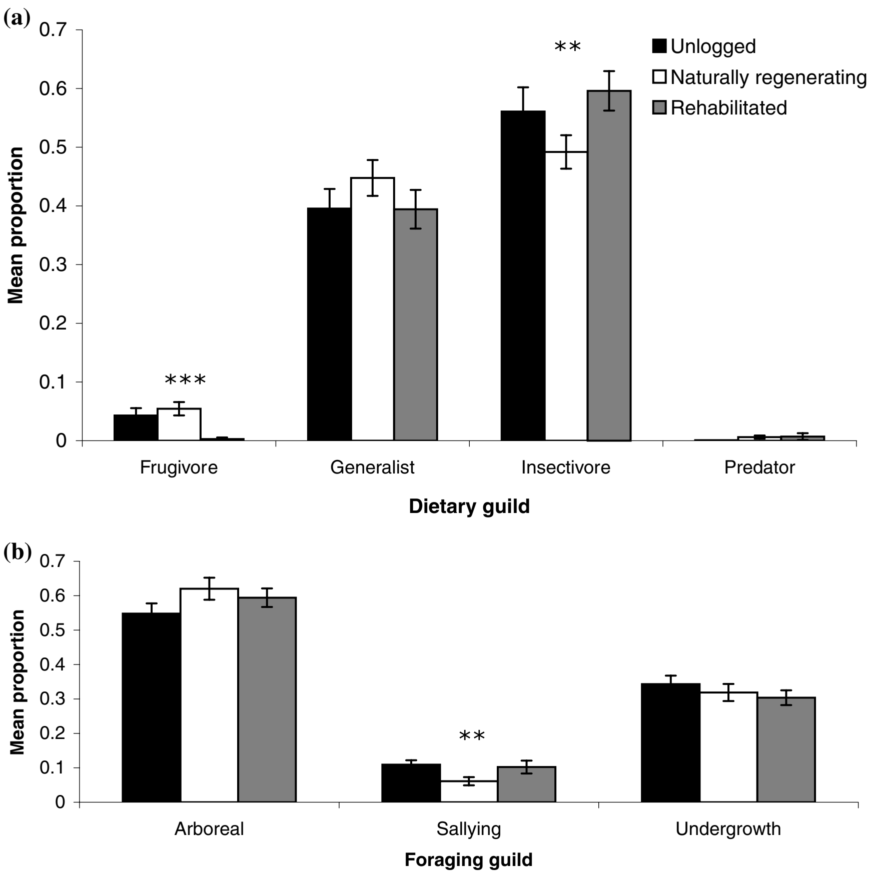

*Figure 2. For each forest type, the proportion of the bird community in each (a) dietary and (b) foraging guild (**p < 0.01; ***p < 0.001).*

previous studies within our study area that were conducted at shorter intervals after logging (Lambert 1992; Johns 1996). In addition, logging had a marked effect on functional composition (Fig. 2, Table 2), and in keeping with the results of many previous studies (see Gray et al. 2007 for a meta-analysis), the abundances of insectivorous species were consistently lower in naturally regenerating forest (Fig. 2). Our results therefore indicate significant long-term effects of logging on avian species richness, diversity, and functional composition, which provide a strong impetus for forest rehabilitation to ameliorate these impacts.

Species richness and diversity of birds were at prelogging levels in rehabilitated, selectively logged forest (Fig. 1; Table 1). The effects of forest disturbance can be strongly influenced by the spatial scale at which habitats are compared, which suggests that care should be taken to adequately sample the range of environmental conditions in both disturbed and undisturbed forest (Hill & Hamer 2004). We sampled over a large area in all three habitats, and so are confident that our results provide the first indication that rehabilitation planting of tropical forests can successfully reverse the effects of logging on biodiversity by promoting succession of faunal communities toward those found in unlogged forest. Moreover, this pattern was evident within 15 years of rehabilitation being implemented, which suggests that the biodiversity benefits from this form of management can accrue rapidly.

Rehabilitation did cause a significant alteration of functional composition (Table 2, Fig. 2). In particular, the proportion of insectivores in rehabilitated forest increased to prelogging levels, whereas rehabilitation resulted in a marked reduction in the abundance of frugivores compared with both naturally regenerating and unlogged forest (Table 2, Fig. 2). This loss of frugivores was driven by two species (*Chalcophaps indica* and *Calyptomena viridis*), the former of which is ubiquitous, but the latter of which has a restricted geographical distribution and is considered near threatened (Birdlife International 2008). Insectivores, particularly salliers, tend to favor tall undisturbed forest (Thiollay 1992), which often has a more open understory (Hamer et al. 2003), while subcanopy and understory frugivores typically feed on small fleshy fruits produced by vines and shrubs (Putz et al. 2001). Thus, these changes in species composition were probably due mainly to liberation cutting. There was also a reduction in the total abundance of birds in rehabilitated forest compared with unlogged and naturally regenerating forest (Table 1). This may have been due in part to lower sampling efficiency in rehabilitated forest, but was probably also the result of liberation cutting. First, many common generalists rely on fruits produced by vines and shrubs (Sheldon et al. 2001). Second, vine tangles trap leaf litter, which acts as an important foraging substrate for insectivorous birds, and vines provide nesting sites and refuges from predators (Putz et al. 2001).

Our results indicate that rehabilitation of selectively logged forest has the potential to improve landscape-scale biodiversity in addition to providing benefits in terms of carbon sequestration. Nevertheless, in view of the adverse effect of forest rehabilitation on the overall abundance of understory birds and on frugivores in particular, we suggest that in future programs some areas within rehabilitated forest should not be subject to liberation cutting. This would increase the availability of dense tangle and shrub microhabitats, which mimic the growth of vegetation within naturally occurring tree-fall gaps that are frequently found in unlogged forests. Forest heterogeneity has a positive effect on the diversity and community composition of a variety of taxa including birds (e.g., Levey 1988), and an increase in heterogeneity of rehabilitated forest could promote additional positive effects on biodiversity.

Clearance for oil palm (*Elias guinensis*) and other such crops is a major driver of deforestation in undisturbed forests and particularly in logged forests of Southeast Asia (Sodhi et al. 2004; Birdlife International 2008). By enhancing their carbon-credit value, rehabilitation provides a strong incentive to protect logged forests and thus complements existing Reduced Emissions from Deforestation and Degradation (REDD) programs (Laurance 2007). In view of the likely additional benefits of rehabilitation for biodiversity, we urge an increased role for rehabilitation of logged rainforests within a biodiversity-friendly carbon-offsetting market.

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