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Understanding drivers of forest diversity and structure in managed landscapes: Secondary forests, plantations, and agroforests in Bangladesh

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ABSTRACT

Managed forests in protected area landscapes may extend the conservation functions of nature reserves, but studies comparing biodiversity between managed forest types have not examined the underlying factors that drive existing patterns. We used linear mixed effects models to test the effects of a suite of biotic and abiotic factors on structure and diversity across both plants and birds in complex agroforests, mixed plantations, and mature secondary forests of the same age in northeastern Bangladesh. We measured woody species structure and composition in 18 0.01-ha plots in each forest type across three forest ranges, and conducted bird surveys using 216 point count stations located among the vegetation plots. Tree species richness and diversity, and avian richness in agroforests were higher than, or similar to secondary forests. However, saplings in agroforests and plantations had lower densities and fewer species than secondary forests, and both managed forest types had reduced regeneration. Our results indicate that agroforests have higher potential to conserve late secondary forest species than plantations, due to specific management practices that manipulate light. This work provides quantitative evidence for the utility of traditional agroforests as a conservation tool, even under high levels of human disturbance. Inadequate evidence has been a key limitation to conservation policy planning in landscapes with both high biodiversity and high human density. We find that managed traditional agroforests are an underutilized option in the conservation of protected areas in a landscape that is characterized by human use.

1. Introduction

Nature reserves ('parks') cover only 14.6% of the terrestrial surface, leaving most global biodiversity to exist outside of formal protected areas (IUCN and UNEP, 2009; Mora and Sale, 2011). Many protected landscapes have been managed by local indigenous people for centuries (Beltran, 2000), and 70–85% of parks currently have human inhabitants (Chatty, 2003). Human-managed systems in and around parks are therefore under increasing consideration for conservation (Daily et al., 2001; Chazdon et al., 2009; Gardner et al., 2009). Managed forests (e.g. traditional agroforests and forest plantations) can be structurally and/or floristically complex, supporting higher native species diversity than non-forest uses such as pasture and annual crops (Gibson et al., 2011). However, few if any studies have investigated the drivers underlying species diversity in managed systems. Understanding the specific environmental factors that influence biodiversity can inform better conservation planning in these landscapes.

There is no substitute for primary forest, but integrating managed forests with conservation is critical, particularly for developing countries in the tropics. A meta-analysis of over 12,000 forest fragments found that wildlife species were able to survive even in small, isolated fragments as long as surrounding habitat matrix was appropriate (Prugh et al., 2008). This has important implications for South Asia, where remaining forest patches are often small, fragmented and embedded in a matrix of mixed land-uses e.g. villages, tea estates and cash crops; and millions of people depend on forests for their livelihoods (Mahapatra et al., 2005). High species diversity often coexists with high human use, yet more information is needed on how vegetation structure in different forest management types practiced across the region affects their relative conservation value (Goodale et al., 2014; Ranganathan et al., 2008; see Bhagwat et al. (2008) for a review). This knowledge gap greatly impedes the development of effective conservation strategies. As debate continues over balancing conservation with other land uses in human-dominated systems, a clearer understanding of how forestry practices affect biodiversity is essential (Perfecto and Vandermeer, 2008). This understanding is also necessary to inform the growing trend to involve

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landscape-level forest restoration and maintenance in conservation policy: A number of recent major international conservation initiatives and agreements such as the Bonn Challenge, CBD Aichi Target 15, and Initiative 20 × 20 of the World Resources Institute, aim to integrate forest restoration with the multiple environmental, social and economic services of landscapes such as enhancing biodiversity and ecosystem functions, and improving rural livelihoods and human well-being (IUCN, 2014; WRI, 2014; CBD, 2010).

We assessed the potential of managed forests to extend or support the ecological functions of secondary forests in northeastern Bangladesh, modeling suites of variables that may explain differences in structure and diversity between these systems. Bangladesh provides an ideal system to examine how managed forests can play a role in tropical conservation. As in many protected areas worldwide, the forests of this region have been inhabited by humans for over a millennium (Poffenberger et al., 2007), and ongoing efforts to end traditional practices or relocate traditional forest dwellers from these lands in order to conserve the forests are highly controversial (Poffenberger, 2000:43). Despite heavy anthropogenic disturbance, species diversity even in the northeastern region alone is high, with nearly 800 woody plant species from 95 families, 246 bird species, and 6 arboreal primates, including the endangered western hoolock gibbon *Hoolock hoolock* (Das and Alam, 2001; Nishat et al., 2002).

We compared floral and faunal diversity in betel agroforests (*Piper betle* L.) and teak plantations (*Tectona grandis* L.f.) to native secondary forests of the same age (>45 years). Secondary forests occur worldwide and are growing in importance for conservation initiatives (Chazdon, 2003), yet few quantitative assessments of their composition exist for stands over 20 years old (Barlow et al., 2007). Betel is a leaf crop that is cultivated under various methods that differ widely across its range, from mainland South and Southeast Asia to islands in the Pacific. In northeastern Bangladesh and India, the people of the Khasia community traditionally plant it in agroforests under mixed native forest canopies in a practice called *bri* or *paan jhum*. Teak is another valuable timber crop throughout South Asia and globally that has been raised in monoculture long-rotation plantations since colonial times. Neither *bri* agroforests nor teak plantations have been evaluated for their conservation value in Bangladesh.

Specifically, we asked (1) How do betel agroforests and teak plantations compare with mature secondary forests in terms of vegetation structure, tree species richness and diversity, and avian species richness and diversity? (2) Do abiotic factors contribute to any differences and if so, how? (3) Are differences in avifaunal richness and diversity significantly associated with forest type and if so, is this due to the physical structure of the habitat?

Based on other studies of biodiversity in managed forest systems, we hypothesized that vegetation structure and species diversity would fall along gradients from plantations to agroforests to secondary forests (Bhagwat et al., 2008; Scales and Marsden, 2008). Bird and vegetation communities are likely to show cross-taxon congruence due to food-web and functional interactions (Su et al., 2004), so we hypothesized that avian richness and diversity would follow patterns of vegetation structure, richness and diversity.

2. Materials and methods

2.1. Study site

Fieldwork took place in Sylhet, northeastern Bangladesh (N 24°01′–25°12′ to E 90°55′–92°30′), from December 2008 to April 2011. We established permanent plots in and around three forest administrative units, or ranges (Fig. 1). The vegetation at the study site covers 747 km^2 and is broadly classified as subtropical wet evergreen/semi-evergreen forest, a forest type that spans 6700 km^2 countrywide, or 44% of total forest land (Bangladesh Forest Department, 2015). Average total annual rainfall for 2000–2010 was 4000 mm, with about 80% of precipitation occurring during the May–October monsoon (BMD, 2011). Average temperatures range from 32.9 °C in April to 9.5 °C in January.

Upland forests of Bangladesh have been managed for centuries, and the northeastern region reflects a mixture of past and present management types. Secondary forests form the majority of natural vegetation, and are much more widespread than primary forest. These are naturally regenerating stands of native vegetation, not actively managed, growing where previously planted timber trees were either legally cleared in wide swathes, or individually felled in smaller patches by poachers. The other two forest management types in the study, betel agroforests and teak plantations, are interspersed irregularly throughout the secondary forests. We chose these two managed forest types over other existing types because they are widespread, constitute some of the oldest managed forests in the region, and because in Bangladesh as elsewhere, there is a drive to promote plantation forestry, while local and indigenous forms of forestry are assumed to have negative impacts on soils and biodiversity (Poffenberger, 2000; Riadh, 2007).

Betel is a culturally and economically important herbaceous vine grown throughout South and Southeast Asia. Its leaves are chewed as a stimulant, as traditional medicine, and for ceremonial purposes (Guha, 2006). In the Khasi *bri* system in Bangladesh, it is raised in forests by planting betel vines at the bases of standing trees (Alam and Mohiuddin, 1995). No large trees are felled, but canopy trees are pruned annually to modify light conditions. Herbaceous ground cover is weeded and used as mulch along with the pruned branches. *Bri* patches are periodically abandoned, due to crop disease, in a practice called *slu* (Fig. 2).

Teak plantations are a major source of income globally, although in Bangladesh timber revenues accrue to the government. They are mostly monocultures, but older plantations can support native species that gradually infiltrate the understory (Lugo, 1992). Local villagers living in and around the forests in the study site are contracted by the Forest Department to carry out silvicultural operations and patrolling, either in exchange for day wages or small allocations of land intended for subsistence agriculture under the "forest villager" program established in the 1950s (Saha and Azam, 2004).

2.2. Study design

Each forest range was treated as a sampling block, and each management type (betel agroforest, teak plantation and unmanaged secondary forest) was considered a treatment that occurred in each forest range. For each treatment, we established six replicate sites that were located across the forest ranges in an unbalanced design, such that each range contained at least one replicate of each treatment (see Appendix A). In each replicate site we randomly located three forest plots for data collection. Therefore we established 18 0.01-ha forest plots per treatment and a total of 54 plots.

All stands used were similar in age class, prior management history, distance to edges with other cover types, and previously unburned according to detailed interviews with local residents and Forest Department staff. The forests were state reserves from the 19th century through the post-colonial period, comprising mixtures of native forest and plantations of varying rotation lengths. They were cleared from 1950 to 1966, then either abandoned (becoming secondary forests) or planted with timber (teak) or betel (agroforests). Details on study system and sampling are in Appendix A.