Sustaining biodiversity in ancient tropical countryside

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With intensifying demands for food and biofuels, a critical threat to biodiversity is agricultural expansion into native tropical ecosystems. Tropical agriculture, particularly intensive agriculture, often supports few native organisms, and consequently has been largely overlooked in conservation planning; yet, recent work in the Neotropics demonstrates that tropical agriculture with certain features can support significant biodiversity, decades after conversion to farmland. It remains unknown whether this conservation value can be sustained for centuries to millennia. Here, we quantify the bird diversity affiliated with agricultural systems in southwest India, a region continuously cultivated for >2,000 years. We show that arecanut palm (*Areca catechu*) production systems retain 90% of the bird species associated with regional native forest. Two factors promote this high conservation value. First, the system involves intercropping with multiple, usually woody, understory species and, thus, has high vertical structural complexity that is positively correlated with bird species richness. Second, the system encompasses nearby forests, where large quantities of leaf litter are extracted for mulch. The preservation of these forests on productive land traces back to their value in supplying inputs to arecanut cultivation. The long-term biodiversity value of an agricultural ecosystem has not been documented in South and Southeast Asia. Our findings open a new conservation opportunity for this imperiled region that may well extend to other crops. Some of these working lands may be able to sustain native species over long-time scales, indicating that conservation investments in agriculture today could pay off for people and for nature.

conservation | working landscapes

The key driver of the destruction of native ecosystems is the demand of growing populations and new consumers for biofuels, meat, and grains (1–3). The resultant land conversion is especially severe in the tropics – especially in South and Southeast Asia – where forests are projected to decline at a faster rate than almost all other biomes globally (under all but the most optimistic assumptions) (4–8). This portends a massive loss of population and species diversity, with likely severe consequences for the provision of important ecosystem services (9, 10). Although protected areas are vital for the conservation of many species, they are probably insufficient to preserve more than a small proportion of the Earth's biodiversity (11). Further, in the face of intensifying human impacts, the capacity of protected areas to sustain biodiversity is likely to erode (12, 13). It is, therefore, critical to find ways of harmonizing agricultural production (1) and biodiversity conservation.

Conservation biologists have typically not paid much attention to agricultural areas in the tropics. This is because few native organisms were thought to be capable of surviving in the countryside, which often differs strikingly in biophysical conditions from native habitats (14). Recent work in the Neotropics in landscapes cleared of native forest in the past century, however, shows that tropical countryside can have value for native species under certain practices. Specifically, the presence of native vegetation and complex vegetative structure interspersed throughout farm fields and grazing areas is critical for native species persistence (15–20).

To assess whether biodiversity can be sustained in tropical countryside over the long term, we sought a study system with 3 key attributes: a long history of continuous agricultural production, intense human pressure today, and remaining extensive natural areas (the last as a baseline for gauging conservation in the countryside). We identified such a study system in the coastal fringes of the Western Ghats mountain range in southwestern India, a global biodiversity hotspot (21). Although this landscape has been continuously cultivated for well over 2,000 years, it still retains significant forested elements (22, 23).

We conducted bird and plant surveys to understand patterns of occurrence for one component of biodiversity: resident birds. The landscape comprises a spatially heterogeneous mixture of relatively intact forest (no extraction permitted, hereafter "intact forest"), production forest (native, but extraction of nontimber products such as leaf litter permitted), arecanut palm plantations, cashew, sparsely vegetated shrubland ("shrub"), rice paddy, and peanut fields. Most of these current land covers have been present for well over 200 years (24). We investigated the first five land covers, omitting the latter two, which seasonally are virtually devoid of native vegetation and wildlife.

Results

We detected 114 bird species in this landscape (raw species richness), with 96% observed outside of intact forest. Sampling across transects seemed to be sufficient, at least on a relative basis, as estimated species richness per site was only slightly higher than raw richness (mean percent increase in site richness with estimator = 15.9% ± 2.8%). This difference in estimated to raw richness varied little across land covers (maximum average difference between land covers = 4.2%). With the exception of shrub, all land covers showed similar bird species richness (Fig. 1*A*, Tukey's Honest Significant Difference (HSD) test, $P < 0.05$) and similar distribution of species across families (calculated on raw richness, ANOSIM statistic R = 0.5499, $P <$ 0.0001) [supporting information (SI) Table S1]. Arecanut palm plantation and production forest were similar in community composition whereas the other three land covers each contained a statistically distinct group of species (calculated on raw richness, ANOSIM R = 0.8051, $P < 0.0001$) (Fig. 1*B*).

The species of greatest conservation concern are those known to be primarily associated with native forest habitat (hereafter "forest species"). We found a total of 51 forest species in this study system (raw species richness). These species were broadly distributed across the landscape, with 46 (90%) found outside of intact forest. Land covers also differed in their forest species richness: again production forest and arecanut were similar and

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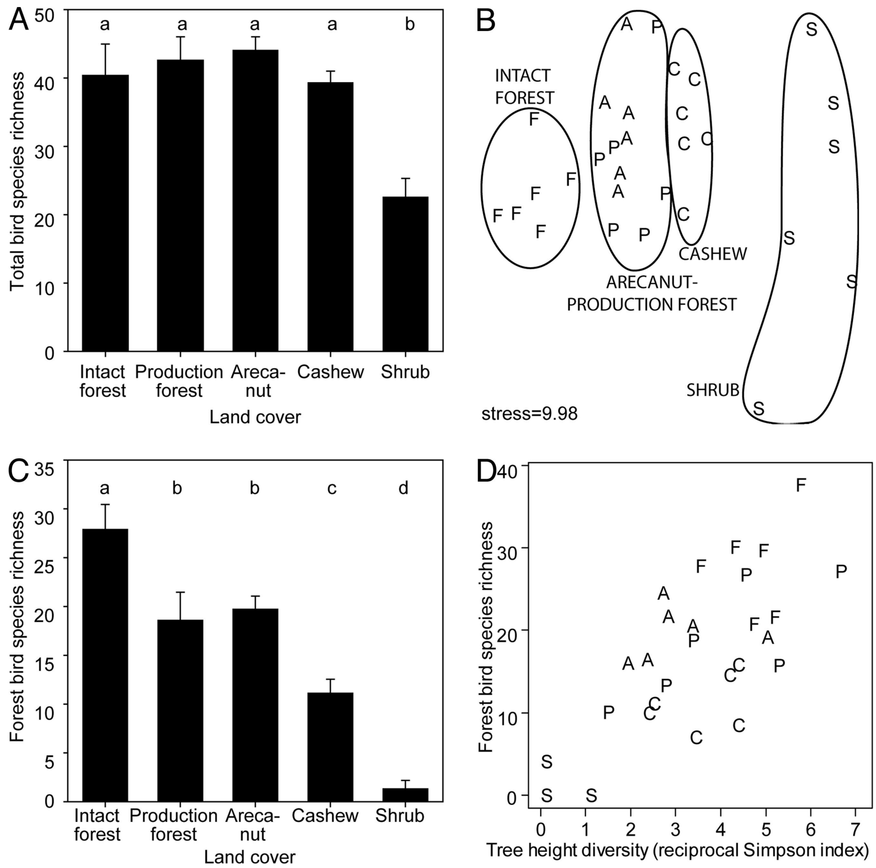

Fig. 1. Patterns of species composition within the study landscape. All species richness measures are estimated using the bootstrap species estimator. (*A*) Total bird species richness, per site, detected within each land cover, with land cover ordered by decreasing structural complexity (standard error noted with error bars). (*B*) Study sites ordinated by species composition using multidimensional scaling. Five land covers are specified as follows: A, arecanut palm; C, cashew; F, intact forest; P, production forest; and S, shrub. (*C*) Forest bird species richness, per site, detected within each land cover. (*D*) Forest bird species richness versus tree height diversity.

second only to intact forest in the number of species detected (HSD test, $P < 0.05$) (Fig. 1*C*). Within arecanut plantations, we recorded such typical (and threatened) forest species as the Great Hornbill (*Buceros bicornis*, 1/3 of sites) and the Malabar Gray Hornbill (*Ocyceros griseus*, 1/2 of sites). As expected, forest species richness was correlated with the vertical complexity of vegetative structure within this agricultural landscape, even after accounting for land cover type (ANCOVA results on species richness, land cover type $P < 0.0001$,and tree height diversity $P < 0.0001$) (Fig. 1*D*).

Discussion

The high conservation value of arecanut, a crop used by 10% of the world's human population (25), has, as yet, gone unrecognized. These arecanut plantations have two additional conservation benefits beyond the forest-like bird community found in them. First, the high water requirements of *Areca catechu* mean that it is usually grown in lowland locations that would otherwise have been dedicated to rice paddy, a production system with a depauperate bird community (26, 27). A crop harboring a forest-like bird community, therefore, occupies land that may otherwise be of little conservation value. Second, the production forests in the area that also show high forest species richness exist largely to provide arecanut production with leaf litter, used as mulch in these plantations. In effect, the production forests and arecanut plantations form a combined cultivation system that contains 76% of the overall bird species pool and 86% of the forest species pool.

Of course, we cannot be certain that no species extirpations have occurred across the landscape since the advent of agriculture. Biogeographical analysis tentatively suggests that the bird species pool of the study site has been relatively stable since before cultivation (28), which began well over 2,000 years B.P. However, survey records for the region from the 1880s exist. Encouragingly, species currently found have >90% overlap with those detected in the 1880s, with much of the disparity attributable to differences in detection methods between time periods (29). Finally, even the most undisturbed tracts of native forest in the Western Ghats exhibit relatively low species richness (i.e., 90 km^2 of well-preserved and mature wet forest within Silent Valley National Park harbors <200 bird species)(28), lending support to the idea that the somewhat low species numbers are a natural phenomenon, not a consequence of human-caused extirpation. Even if human-induced extirpations have played a major role throughout time in reducing the number of species found in this landscape, the point remains that this production system sustains a rich avifauna compared with many other agricultural areas cleared from tropical forests (e.g., oil palm plantations) (30).

It is important to emphasize that it is the traditional cultivation method that produces important biodiversity benefits for arecanut plantations. This agricultural practice also has large economic benefits for farmers, because arecanut plantations produce betel nut, which is a mild, coffee-like stimulant with high economic value (27). The economic value of these plantations is only increased by the fact that, with traditional methods, arecanut is grown interspersed with other high value crops like vanilla and pepper (27). In our study system, pepper, banana, and coconut, and sometimes other economically valuable plants, were intercropped with the arecanut; a range of fruit-producing trees often lined cultivation edges. Consequently, arecanut adds to the conservation case for traditional agriculture, which has been used in India and elsewhere in the tropics to support local livelihoods and biodiversity (31, 32).

Our results show that agricultural landscapes in the Palaeotropics, under the right configuration and management, can sustain and support human livelihood and substantial bird communities of conservation concern over the long term. This gives hope that more recently cleared agricultural countryside can do the same for its avian species and other components of biodiversity (33, 34). The arecanut-forest plantation systems described here have the potential to be a key partner for bird conservation throughout the production range of South and Southeast Asia, as shade coffee is important for conservation in Latin America (30). Our findings further suggest that other keys to sustaining biodiversity may lie in systems with traditional practices, perennial structural complexity, and high economic value.

Methods

The study area (located in Uttara Kannada District, Karnataka, India) extended over 20 kilometers on the coastal fringes of the Western Ghats Range (Fig. S1). We positioned six 200-m transect lines within each of the five land covers (a total of 30 transects). The transect-line was termed a ''site.'' Each site was separated from all others by at least one kilometer, and all were $<$300 m in elevation. Each was surveyed seven times, March–June, 2004, between 6:00–9:00 a.m., by an observer who slowly walked a transect for 30 min, noting all resident birds within 50 m of the line. We noted only species detections, and not behavioral information, for detected individuals. All seven surveys were pooled for each site. The number of bird species detected at each transect was transformed to estimated richness by using the bootstrap estimator (35). We also determined plant composition and structure at each site, and measured canopy closure with a densitometer, at 20 m intervals along a transect (11 densitometer readings per site). At each site, the height, girth, and species identification of all trees with diameter at breast height $\geq$10 cm, were recorded in two randomly placed 20 $\times$ 20 m quadrats. Height was estimated and placed into one of four categories: 0–5 m, 5–10 m, 10–20 m, or 20–30 m. The same height categories were used to calculate the tree height diversity for each quadrat by using the reciprocal Simpson Index. Within each quadrat, the height and species identification of each shrub was noted in two subquadrats (10 $\times$ 10 m). Only tree height diversity is mentioned in the main text, because it is the only metric that significantly correlated with bird species richness.

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