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Achieving production and conservation simultaneously in tropical agricultural landscapes

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ABSTRACT

Increasing population size and demand for food in the developing world is driving the intensification of agriculture, often threatening the biodiversity within the farmland itself and in the surrounding landscape. This paper quantifies bird and tree species richness, tree carbon and farmer's gross income, and interactions between these four variables, across an agricultural gradient in central Uganda. We showed that higher cultivation intensities in farmed landscapes resulted in increased income but also a decline in species richness of birds and trees, and reductions in tree carbon storage. These declines were particularly marked with a shift from high intensity smallholder mixed cropping to plantation style agriculture. This was especially evident for birds where significant declines only occurred in plantations. Small scale farming will likely continue to be a key source of cash income for the rural populations, and ensuring 'sustained agricultural growth' within such systems while minimising negative impacts on biodiversity and other key ecosystem services will be a major future challenge.

1. Introduction

Increasing food demand as a result of increasing human population size, urbanisation, and dietary changes towards animal products and processed food is placing enormous pressure on agricultural land. Currently, agriculture occupies approximately 38% of the Earth's terrestrial surface and is expanding, particularly in the tropics (Foley et al., 2011) where it is the primary cause of deforestation (Geist and Lambin, 2002). Indeed, Gibbs et al. (2010) found that during the period 1980–2000 more than 55% of new tropical agricultural land was derived from intact forests, and another 28% came from disturbed forests. Agriculture is a key driver of many environmental threats including biodiversity loss, habitat degradation, soil erosion, water security, pollution and climate change (Sala et al., 2000; Foley et al., 2005; Green et al., 2005; Millennium Ecosystem Assessment, 2005; Power, 2010). In the tropics, agriculture threatens the environment largely due to the expansion of crops and pastures into areas covered by diverse natural or semi-natural, fallow vegetation (Geist and Lambin, 2002; Millennium Ecosystem Assessment, 2005; Gibbs et al., 2010) and, to a lesser extent the increasingly intensive management of land already under production–including increased use of agro-chemicals (Snapp et al., 2010). However, food production and biodiversity are not always mutually exclusive and there is evidence that in some situations, primarily tropical smallholder agriculture systems, high crop yields and high biodiversity can coexist (Pretty et al., 2006; Steffan-Dewenter et al., 2007; Perfecto and Vandermeer, 2010; Clough et al., 2011). In many developing regions and in Africa and Asia in particular, smallholder farming remains the dominant form of land use and so a central challenge will be to improve yields and farm income while maintaining biodiversity and landscape function (e.g. carbon storage Wade et al., 2010). However, datasets integrating biodiversity with production or income variables are scarce (but see Clough et al., 2011; Phalan et al., 2011; Hulme et al., 2013). In this study, we use bird and tree

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species richness as a measure of biodiversity, tree carbon, and gross farm income, and assess the interactions between them. We do this along an agricultural intensity gradient in central Uganda, north of Lake Victoria, commonly referred to as the banana-coffee arc. Specifically our aim is to characterise the impacts of agricultural land use intensity on farmer livelihoods and biodiversity in a tropical agricultural system and evaluate the nature of any trade-offs or synergies between farm income and farmland biodiversity.

2. Methods

The study area lay within the banana-coffee farming system surrounding Lake Victoria, central Uganda and covered ca. 50,000 km^2. The area had a relatively high human population density, ranging from 75 to 600 people/km^2 and comparatively good access to infrastructure and markets (Bolwig et al., 2004). The major land use in the area was perennial crops, primarily banana and coffee, with an increasing shift towards cultivation of annual crops in recent years. The study was conducted at 26 sites across the area, each 1 × 1 km square in size and containing between 40 and 60 farms ranging from landscapes with a low cultivation intensity of approximately half fallow, half cultivated to high cultivation intensity landscapes that are entirely cultivated. Twenty-two of the sites were on smallholder farms, two were on coffee plantations, one was on a tea plantation and the remaining site was on a sugarcane plantation. The sites were selected to be broadly representative of the agricultural landscape and systems and encompassed two ‘gradients’ in the region: (i) population density derived from the 2002 Ugandan National Census (www.ubos.org) used as a surrogate for cultivation intensity; (ii) farm type covering both smallholder farms characterised by mixed farming, low levels of mechanisation and low use of agro-chemicals even at high levels of cultivation intensity, and plantations characterised by mono-cropping and high input use. At each site we measured the composition and intensity of agricultural land use, as well as the amount of tree carbon stored, total crop income, and the species richness of birds and trees.

2.1. Land use

We conducted a physical survey in 2007 of land use at each of the 1 × 1 km squares, hereafter called sites, by recording the type of land cover found along five parallel transects across the site, each of 1 km in length and separated by 200 m. The length of each habitat on each transect was recorded and mapped using a hand held GPS unit. The most common land use types were agricultural crops, pasture, natural vegetation and semi-natural (fallow) vegetation. Each crop was identified and recorded separately. From these one-dimensional measures of land use, the area or percentage of land covered by each type of vegetation at each site was estimated by assuming uniformity in land cover between one transect and the next. The cultivation intensity of each site was calculated as the area covered by crops or managed pasture divided by the total agricultural area in the site and expressed as a percentage. Land cover types such as water bodies, houses and virgin forest were not considered. Cultivation intensity increased linearly with population density validating post hoc our method of site selection ($t = 7.65$, $P < 0.001$).

2.2. Bird species richness

The abundance and species richness of birds was measured using two methods at all 26 sites between February 2006 and January 2007: point counts (PCs) and 10 min. timed species counts (TMCs). Surveys at the 26 sites were carried out over five visits, at least six weeks apart, in the mornings (07:00–12:00 h) and the evenings (17:00–18:30 h) avoiding adverse weather conditions (Nalwanga et al., 2012). During each survey, counts were carried out at 10 stations, 200 m apart, along a 2 km transect within each site over a two day period. Transects were located at random but were often positioned along existing small tracks and pathways through the site to avoid trampling of cultivated land. During PCs, all birds seen and heard within a 100 m radius were recorded for a period of 10 min and allocated to one of three distance bands: 0–25, 25–50 and >50 m from the centre of the point-count station. TMCs were conducted as PCs above, using the same stations but the observer was free to move around the study plot (i.e. within 100 m radius of the point). This yielded 50 PCs and 50 TMCs at each site, with the exception of four sites, two plantation sites of which were only visited three times and hence had 30 counts for each method, one where only eight stations were surveyed on each visit yielding 40 counts for each method and one which had 50 TMC but during one visit no PC were taken hence 40 PCs.

2.3. Tree species richness

Woody vegetation was sampled at each site between April 2006 and March 2007 using the same five parallel transects as in the land use survey (see above). The number and species of woody vegetation were recorded in 20 circular plots of 20 m radius in each site. All young plants less than 2.5 cm diameter at breast height (DBH) were classified as saplings. Woody plants above 2.5 cm DBH were recorded in classes of 2.5–4.9, 5.0–9.9, 10.0–29.9, 30.0–49.9 and >50.0 cm. Enumeration of all the plants within 1 km^2 was only possible for plantation sites where scattered trees were scarce.

2.4. Crop income

The total monetary value of crop production was calculated for each site as the sum of the market value of all crops harvested at each site in the 12 months between September 2006 and August 2007. This time period covered both a minor and a major crop season. The value of each crop was calculated by multiplying the area covered by the crop with the crop yield per area unit and the farm gate price, which was taken as the mean of market surveys in both seasons. The crop area was estimated through the land use survey (see above). The yield was calculated as the simple average of the yields obtained by questionnaire interviews with six farmers located in each of the 22 smallholder sites. The six farmers were randomly selected from a larger sample of 10 farmers in each site who met the following criteria: at least 50% of their land must be under cultivation, they must together produce all the major crops identified in the land use survey, and their farms must be broadly typical of the area (for more details see Hulme et al., 2013).

2.5. Tree and root carbon

Above ground tree carbon and root carbon were calculated using tree size data collected in the woody vegetation survey. Based on Kaonga (2005)'s study, we used the below equation to calculate tree biomass which, for trees between 5–148 cm DBH, most closely estimated above ground tree carbon stocks:

Tree biomass = $0.118D\hat{2}.53$ (Brown, 1997).

The DBH of each of the trees measured in the woody vegetation survey, taken as the median diameter (D) of the tree size class it was grouped in for those in size classes 5–9.9, 10.0–29.9, 30.0–49.9 cm DBH and the minimum diameter for those in the >50.0 cm DBH class, was used to calculate tree biomass (sapling and trees below 5 cm DBH were not included) using the above equation. Assuming a carbon content of 0.5 g C/g dry matter (IPCC, 2006) the above-ground carbon stocks at each site, excluding the four plantation sites, was calculated and converted into t/ha. Root carbon was taken as 30% of above-ground tree carbon (Saint-André et al., 2005;