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Article

Assessment of Pest Control Services by Vertebrates in Nigerian Subsistence Maize Farms

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Abstract

Global conversion of patches of natural vegetation into agricultural land is reducing the ecosystem services provided by natural patches dwelling species to farmers. For sub-Saharan African subsistence farmers, such a reduction in pest control services by birds may be a significant disadvantage. Here we explored to what extent birds provide pest control services to the staple crop maize (*Zea mays*) on small subsistence farms on the Mambilla Plateau of Taraba State, Nigeria. We used exclosure experiments (maize crops with and without birds) to model how birds influenced crop yield. We found that excluding birds from maize significantly reduces crop yield, although the lack of a direct correlation between bird abundance and crop yield suggests that other taxa, such as bats, may also be important pest predators. Our results suggest that in this subsistence farming landscape, natural pest control of maize from vertebrates does occur, but further research is needed to understand the specific control agents and the role of patches of natural vegetation as habitat for them.

Keywords: Subsistence maize farm, exclosure experiment, birds, pest control services, crop productivity

Link to supplementary material and data file: https://bit.ly/3Ak9E6R

INTRODUCTION

Africa's human population is growing faster than anywhere else and is predicted to comprise almost two-thirds of the global population increase between 2020 and 2050 (WPP 2019). In sub- Saharan Africa, increased food production associated with such population growth is predicted to come from subsistence farms rather than from increased farm intensification (Davis et al. 2017; Laurance et al. 2014). Thus, patches of natural vegetation will continue to be converted to crop-land with major implications for biodiversity and associated ecosystem services (Malhi et al. 2014; Whelan et al. 2015; Whelan et al. 2008). In Africa, biodiversity hotspots, including the Cameroon highlands (Ezealor 2002; Fishpool and Evans 2001) are especially vulnerable because they share both a high propensity for farmland expansion and high levels of endemism (Zabel et al. 2019).

One way to counter habitat loss and protect biodiversity is to demonstrate to farmers the economic benefit of maintaining patches of natural habitat for the ecosystem services they provide (Garcia et al. 2020; Marcacci et al. 2020). This approach has been successful in several locales across a range of cropping systems; for example, several recent studies have shown insectivorous birds to be effective controllers of invertebrate pests in large scale farming operations and plantations in tropical agroecosystems (Classen et al. 2014; Karp et al. 2013; Maas et al. 2015). Birds have been shown to directly reduce infestation rates of invertebrates and indirectly increase crop productivity in coffee plantation and apple orchard (Kellermann et al. 2008; Mols and Visser 2002).

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However, in sub-Saharan Africa a dearth of studies means that very little convincing evidence is available to subsistence farmers to suggest that conserving natural habitats may benefit crop yield. Only one study that we are aware of, from East Africa, has assessed the role of insectivorous birds in regulating herbivorous arthropods on maize farms (Otieno et al. 2019). For other crops, a study from Kenya (Miligan et al. 2016) demonstrated that both forest birds and ants made significant contributions to pest control in highland coffee plantations, and Ndang'ang'a et al. (2013) quantified the contribution of insectivorous birds in controlling insect pests on the brassica crop *Oleracae acephala*.

Across sub-Saharan Africa, *Zea mays* is the second most-produced staple crop (FAO 2017), with the land area used for growing maize having increased by 60% between 2007 and 2017 (Santpoort 2020). Most producers are small, often subsistence farmers who cannot afford pesticides (Zhang et al. 2018), a common situation in Nigeria (Richard 2014). In sub-Saharan Africa, maize is attacked by a myriad of invertebrate pests which contribute to lower crop yields to well below the worldwide average (SFSA and Syngenta 2020). Herbivorous insects of maize, such as the maize stem borer (Lepidoptera: *Busseola fusca*) and pink stalk borer (Lepidoptera: *Sesamia calamistis*) are major pests (Adamu et al. 2015; Oben et al. 2015; Zakari et al. 2014) and in Nigeria can reduce yields by 12 - 50% (Adamu et al. 2015). How vertebrates such as birds, bats and rodents contribute to pest control in subsistence food crops such as maize (Cadoni and Angelucci 2019), needs to be better understood.

In Nigeria, subsistence farms often form a patchwork within a semi-natural environment comprising degraded grassland, scrubland or patches of natural vegetation that are at varying distances from the farmlands. Crop plants (e.g., maize crop plants) may depend on these habitats for pest control services by vertebrates because trees provide breeding habitats or refuges. Here we chose to focus on birds as control agents because among vertebrates, birds exhibit the most diverse range of ecological functions (Sekercioglu 2006), and are known to provide important ecosystem services elsewhere (Whelan et al. 2015) .

Our overall hypothesis was that, birds, by predating on invertebrate pests of maize, allow for increased maize yield. We made two predictions: 1) that the proportion of cob and leaf damage caused by insect herbivory on crops will be higher in the bird excluded treatment, which will in turn negatively affect crop yield, and 2) that crop yield will be highest where birds are most abundant. Our specific objectives were to test; 1) whether excluding vertebrates (e.g., birds and bats) from maize crops leads to a reduction in crop yield and, 2) if there is a relationship between bird abundance and maize crop yield.

MATERIALS AND METHODS

Study area

Our study took place in the farmlands along the north western escarpment of the Mambilla plateau in Taraba State (7.16°N, 11.66°E), SE Nigeria, close to the Nigerian Montane Forest Project (NMFP) field station. There is a distinct wet and dry season with a mean annual rainfall of around 1700mm (Chapman and Chapman 2001). The minimum average monthly temperature ranges from 15.5-18.5 °C and the maximum from 27.5-30.5 °C (Matthesius et al. 2011). The plateau, with an average elevation of 1,600 m is characterised by gently undulating hills covered in overgrazed *Sporobilis* grassland, with a loose patchwork of small subsistence farms mostly associated with villages and patches of natural vegetation. Annual food crops grown in the farms include maize, ginger (*Aframomum melegueta*)*,* groundnuts (*Arachis hypogea*), kidney beans (*Phaseolus vulgaris*), potatoes (*Soloanum tuberosum*) and yam (*Dioscorea rotundata*). A year-long bird survey, conducted as part of a wider study associated with this research, showed that insectivorous birds are an important component of the bird fauna, comprising over 50% of all avian species in the area (Tela 2019). For the experiment, we selected 20 maize farms situated at varying distances from the natural habitats (Figure 1). All farms were free from pesticide use and were at least 200 m apart from each other. The willingness (or otherwise) of farmers to allow work on their land, placed a limit on the number of farms included in the study.

Study design and sampling

Exclosure experiments were conducted during the wet season April – October 2017, when maize is traditionally cultivated on the Mambilla Plateau. In each of the 20 farms studied, farmers had planted their maize seeds in early April as part of their routine maize planting schedules. Thereafter, we established one 20 x 10 m plot on each farm and subdivided each plot into three 6.7 x 10 m subplots. One of the three subplots was retained as a control treatment (open access), one was designated as a bird exclusion treatment, and one as birds + insects-excluded treatment. The exclosures placed in

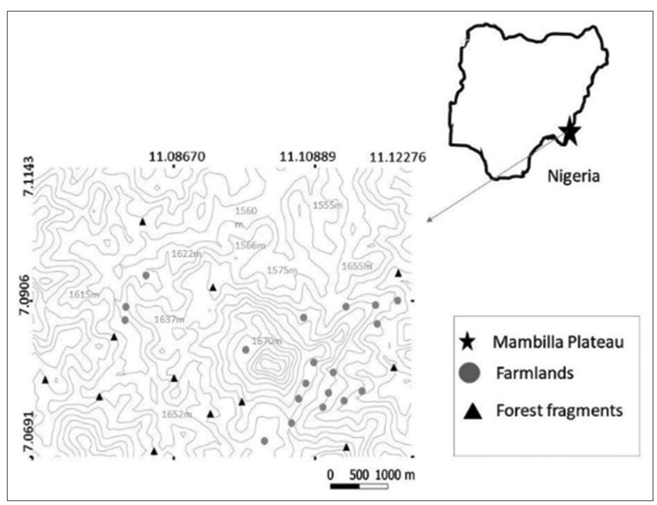

Figure 1
Map of Nigeria and the location of the experimental site on Mambilla Plateau, Nigeria

the 6.7 x 10 m subplots were each approximately 4x4x4 m, with a distance of 2.5 m between each subplot.

All cages were built with wooden frames; the bird-only exclusion cages were covered with agricultural wire netting with pore size of 0.8mm x 1.2mm, allowing for insects to enter while excluding birds. The bird + insect exclusion cages were covered with mesh of pore size 0.1mm x 0.1mm. The cages were placed in the respective subplots as soon as the maize seedlings germinated. Each cage was placed over three maize plants and staked down. Care was taken to arrange the netting to make leaves inaccessible to hovering birds and deny entry of ground-foraging birds. In the control (i.e., open access) three maize plants, of similar proximity to each other as the three plants in the exclusion cages were identified and tagged with pink ribbons as control plants.

For each treatment, when the maize cobs were ripe, we harvested the ripe maize cobs from each of the three plants in each of the three treatments across the 20 farms twenty-one weeks after planting, in September. First, the number of cobs from the three experimental crops in each treatment was counted, and the husks were peeled off. Any holes in the kernels, caused by invertebrate herbivores (hereafter referred to as damaged cobs of maize), were also counted and recorded. The cobs were then dried on a mat exposed to sun and wind, until they reached a constant weight, using a digital Camry mechanical weighing scale (NS 5 - 20 kg). At the time of harvest, we also assessed damage by phytophagous insects on each plant from each treatment. Leaf damage was visually estimated as the percentage of leaf area damaged by herbivores, relative to the total leaf area (Morrison and Lindell 2012). We considered damage as perforated, skeletonised, curled or partly cut leaves (Lemessa et al. 2015; Morrison and Lindell 2012; Van Bael et al. 2003). To control for possible differences in leaf damage before the experiment began, we checked to see if there was any leaf damage following the sprouting of maize plants but found none.

Bird abundance assessment and classification

We sampled birds in each location using point counts (Bibby et al. 2000). Each farm was surveyed once per week between 6:30 am to 10:30 am, logistically we were unable to work at night during our study. We spent 10 minutes on focal observation of birds and recorded birds within a 50 m radius at each experimental plot. Observations were made along the edge of the experimental plots to avoid any form of disturbance. In the analysis, all birds that included insects as part of their diet, even though insects may not be a primary component of their diet, were included in the dataset (Borrow and Demey 2001; Bregman et al. 2014; Wattel 1993). These species make up the trophic functional group that is likely to be providing pest control services to the farmlands.

We classified each bird to habitat categories according to whether they are 1) farmland 2) forest fragments or 3) in both farmland and forest fragments, using habitat association information found in Bibby et al. (2000), and Wattle et al. (2003). We also categorised each bird occurrence within the understory (ground-foraging omnivores), midstory (aerial foliage gleaners) and the upper story (upper strata). This is important because tropical studies have shown that 1) the understory insect eating birds are highly impacted by natural habitat modifications (Bregman et al. 2014; Buechley et al. 2015) making them good indicators of habitat quality (Whelan et al. 2015), and 2) the understory insect eating birds contribute to pest control services to coffee farmers in East Africa and in other regions of the world (Buechley et al. 2015; Otieno et al. 2019), and may be of economic importance to maize farmers in Nigeria (see Appendix 2 for a list of species and their classification).

Statistical analysis

All statistical analyses were carried out using the R statistical package version 3.5.6 (**R** Core Team 2018). We calculated the means and standard errors of crop yield, cobs damage and leaf damage across the three treatment (Table 1), and then we used general linear mixed effects models (GLMMs) to test whether the abundance of birds had any effect on crop productivity as measured by crop yield, leaf damage and cobs damage. Our initial experiments included three treatments: 1) open access (subsequently referred to as control) with no exclusion (birds + insects present), 2) birds only excluded, 3) birds + insects excluded. Unexpectedly, crop yield, cob and leaf damage measures for both exclosure types were very similar, suggesting that insects were not excluded completely from the cages that were intended to exclude both birds and insects (Appendix 1). Therefore, because this was considered to be a failure of experimental implementation, we re-ran the models using bird exclusion and control treatments only and concentrated on the effects of excluding birds versus the control treatment only.

To address the objectives of the experiment, we used general linear mixed effects models (GLMMs) to test whether crop productivity, as measured by crop yield, cob damage and proportion of phytophagous leaf damage, was influenced by 1) bird exclusion and 2) bird abundance. For each objective we modelled crop productivity as a function of the abundance of insectivorous birds, with treatment and bird abundance as fixed effects and plot as a random effect. All model selections were carried out using the information-theoretic approach based on Akaike's Information Criterion (Burnham and Anderson 2003). Simplification of models was undertaken using deletion of least significant effects from an initial full model. In all cases, a statistical significance level of $p<0.05$ was chosen to reject the null hypothesis.

RESULTS

We recorded 3,343 birds belonging to 165 different species across the 20 farmlands. Over 50% of the bird species included insect as part of their diet (Tela 2019). Eighty-seven species are understory insect eating birds, 60 species are midstory insect

Table 1
The mean (± SE) of crop yield, damaged cobs and % leaf damage in three experimental treatments (insect and birds excluded from crops, birds only excluded from crops and crops accessible to birds) across 20 farmlands

Replications (40 points)			
Parameters	**Insect and birds excluded**	**Birds excluded**	**Open access**
Crop yield (g)	244.13±35.67	306.33±47.87	773±48.35
Cobs with damage	0.025±0.025	0.13±0.064	0.075±0.075
Percentage of leaf damage	0.55±0.84	2.075±1.047	-0.55±1.047

eating birds and 18 species are upper strata species. In total, we recorded a crop yield of 28,063g from the control treatment and 16,030g from the bird excluded treatment.

The exclusion of birds from the maize plots led to reduced crop yield and increased cob and phytophagous leaf damage (Table 1).

While crop yield was significantly higher in open plots than in bird-excluded ones, it did not increase as insectivore abundance increased (Table 2A and Figure 2). Moreover, there were no significant differences in cob damage across treatments or with abundance of insectivorous birds (Table 2B). However, leaf damage was marginally significatly lower in the open treatment relative to the bird excluded treatments (Table 2C).

Table 2
The relationship between crop yield, damaged cobs and percentage leaf damage and bird abundance in the two treatments (birds only excluded from crops and crops accessible to birds) across 20 farmlands

Variables	Estimate	SE	*t*	*P*
A. Crop yield model (AIC=1145.62)				
(Intercept)	216.82	146.67	1.48	0.147
Insectivorous birds	6.29	9.74	0.65	0.522
Open access	466.68	57.21	8.16	**<0.001**
B. Cobs with damage model (AIC=102.02)				
(Intercept)	0.11	0.19	-0.59	0.556
Insectivorous birds	0.017	0.012	1.35	0.183
Open access	-0.05	0.1	-0.51	0.613
C. Leaf damage model (AIC=522.26)				
(Intercept)	3.06	2.6	1.18	0.247
Insectivorous birds	-0.03	0.17	-0.18	0.859
Open access	-2.63	1.36	-1.94	0.06

Notes: Bird excluded was set as the intercept. Significant *P* values is given in bold.

DISCUSSION

Our study adds to only a handful of previous studies from Africa into crop pest control by birds (Milligan et al. 2016; Ndang'ang'a et al. 2013; Otieno et al. 2019) and is the first from sub-Saharan Africa, as far as we know, to assess the effect of pest control provided by birds on maize yield in subsistence farmlands. We have demonstrated that excluding birds as well as other vertebrates from maize plants at our study area leads to a significant reduction in crop yield compared with plants on which vertebrates have open access. We have therefore strong evidence that natural pest control may increase crop yield.

About 90% of the birds recorded in our study use both the farmlands and patches of natural vegetation. It is possible that some of the birds from the natural habitats were foraging in the maize farms, providing valuable ecosystem services. On the other hand, the farms may serve as stepping-stone or corridors for forest birds searching for more suitable habitat, emphasising the need for effective conservation of seminatural habitats in montane regions.

With regard to guild, our maize farms support a high number of understory insect eating birds e.g., the Rufous-naped Lark (*Mirafra Africana*), Common (African) Stonechat (*Saxicola torquatus*), Northern Grey-headed Sparrow (*Passer griseus*) and Common Bulbul (*Pyconotus barbatus*). This particular group of bird species may be of economic importance to maize farmers in Nigeria, as shown in other region of Africa e.g., in East African coffee farms (Buechley et al. 2015). However, the understory insect eating birds are among the most susceptible of groups to disappear from natural habitat disturbance (Arcilla et al. 2015; Cordeiro et al. 2015; Powell et al. 2015; Şekercioḡlu et al. 2002). Therefore, in order to conserve these birds for pest control services to farmers in a long term, it is important to conserve semi natural habitats in Nigerian agricultural landscape. We also recorded a good number of the midstory insect eating birds, most of which are aerial foliage gleaners and may play an important role in insect pest control in the maize farms, e.g., Common Fiscal (*Lanius collaris*), Orange-tufted Sunbird (*Cinnyris bouvieri*), and the Cisticolas (in large numbers).

We found a total drop in maize yield of 12.03kg/ 4.5km^2 when plants were caged and protected from birds, relative to the yield from uncaged plants. Based on these data, and the dollar value of maize in local markets, we estimate that losing birds from Mambilla plateau farms would cost farmers between 14 – 25 US$ per hectare. This is based on the following assumptions and reasonings; maize is worth approximately 1.2US$/kg (i.e., the price of foodstuffs in Nigeria 2020). The values used in our estimations were based on local maize prices in rural areas. However, given that the price of maize substantially increases as it is traded from farm to wholesalers and ultimately to retailers and consumers (Eyitayo et al. 2019; Kaminski et al. 2013), the actual ecosystem service of insect pest control by birds or other vertebrates may be substantially higher in situations where this supply chain operates. In addition to the benefit of natural pest control on crop yield is the reduced need for pesticides. This is beneficial both in reducing pesticide dollar costs and their detrimental effects on both human health and the environment (Muller et al 1997).

Our study, in demonstrating that natural pest control may increase crop yield on Mambilla subsistence farms, has set

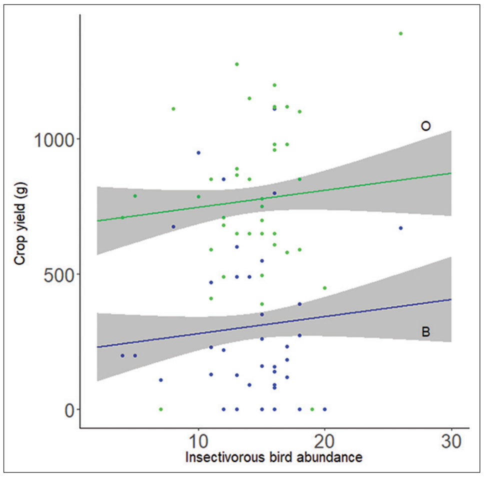

Figure 2
Relationship between crop yield and abundance of insectivourous birds across treatments; O – open access and B – Birds excluded. Shaded areas represent ±1 SE. Predicted lines plotted from the model in Table 2A: change in yield with abundance is not significant, but differences according to treatment are

the scene for future research. There were several limitations to our study. First, our exclosure experiments were not all successful- future work must make sure that there is a third treatment with both birds + insects excluded. This is important because it should theoretically tell us what proportion of the change in yield is directly due to insects. Secondly, the birds + insects exclosure itself may have decreased yield in this treatment because of the negative effect of the mesh on growing conditions (e.g., through shading or microclimate). Another potential effect of the mesh may have been on pollination; maize is mostly wind pollinated and the cage meshing may have slowed wind flow past the maize. Consequently, we have based our conclusions on just the data from control (open) plots versus bird excluded plots. Thirdly, we did not identify which pest species were most attracted to maize, nor the insectivores most active on maize plants.

The lack of any relationship between insectivore abundance and yield in our study may be partly due to the ecology of maize and/or Mambilla subsistence farmlands, our experimental design) or perhaps, a combination of both ecology and design limitations. For example, not all insectivorous birds necessarily include maize plants as an important source of insects, especially if other crops in the system are more attractive to phytophagous insects. Possibly one, or a few birds present were responsible for the observed levels of pest control (e.g., Jedlicka et al. 2011; Maas et al. 2015). Alternatively, there may be other key biocontrol insectivores of maize pests involved, such as bats and possibly rodents. Bats are known to predate on phytophagous insects elsewhere (Williams-Guillén et al. 2008) and are common in the farmlands of our study area (pers. obs. MT, HC). Moreover, many herbivorous insects are nocturnal (Maas et al. 2013; Morrison and Lindell 2012), as are bats. Due to logistical constraints, we were unable to test for bats – this would have involved going out at dawn and dusk to remove and replace cages and the security situation on the plateau did not allow for this. Nevertheless, our exclosure experiments were closed all day and night, so technically we excluded both birds and bats. Although, rodents can also improve crop yields by feeding on insect pests, rodents are known to cause significant damage to a range of agricultural crops (e.g., maize, wheat, rice and groundnuts) worldwide (see Brown et al. 2007; Labuschagne et al. 2016). For example, the house mouse (*Mus musculus*) is responsible for most of the postharvest crop damage caused by rodents in Africa (Ognakossan et al. 2016). Thus, future studies should investigate the relationship between the presence of rodents and crops in Nigerian subsistence farmlands.

While we did not show a strong effects of excluding birds on cob and leaf damage, as might have been expected given the drop in yield, insect damage to crops often extends beyond leaf herbivory (Morrison and Lindell 2012). For example, a significant proportion of insect pests of maize may not attack leaves, or at least do not make holes that significantly reduce leaf surface area (De Groote 2002; Ofor et al. 2009), but may attack maize stems (Tremblay et al. 2001). For example, in the case of the stem borer, birds may catch the moths and therefore reduce the number of larvae in the stems. Aphids are phloem-feeding insects (Morrison and Lindell 2012) that can severely damage plants, leading to reduced yield, yet do not necessarily reduce leaf surface area by creating holes (Goggin 2007; Zangerl et al. 2002).

Future research should seek to establish if the ecosystem and economic services provided by birds in maize farms are widespread in Nigerian farmlands and other maize- growing regions across Africa. If they are, and if birds (or bats) depend on patches of natural vegetation, and if this is explained to local communities, it may provide a powerful incentive for conservation of natural habitat.

Author contribution statement

Conception and design of the research: MT, WC, HC. Data collection: MT. Data analysis: MT, WC. Drafting of manuscript: MT. Intellectual contents to the drafts and critical revision of manuscript: MT, WC, HC. Final approval of the version to be published: MT, WC, HC.

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Declaration of competing/conflicting interests

The authors declare no competing interests in the conduct of this research.

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Research Ethics Approval

Not applicable. This research does not require an ethics approval.

Data Availability

All data are fully available without restriction. We have provided the data in a separate supplementary information file (cs_20_213_Tela et al_data file.xlsx).

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