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Body size, richness, and abundance of Staphylinidae unaffected by landscape composition and cropping system in a push–pull maize system in Kenya

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Abstract

The change from predominantly natural to agricultural landscapes has been shown to reduce pollination and biological control services and also affect the functional traits of the insects that provide such services. Research shows that increasing agricultural area at the landscape scale can have variable effects on functional traits such as body size in predators. Moreover, local factors such as farm management strategies have also been shown to affect functional traits in insects. Studies of local or landscape effects on functional traits are often contradictory in temperate regions, and absent from tropical regions. In Kenya, local pest management technologies, e.g. push–pull systems have been shown to increase biological control, but data is lacking on how local management could affect body size of natural enemies. We investigated how the proportion of natural areas in the landscape and local management (push–pull) affected the body size of rove beetles (Staphylinidae) in Kenyan maize fields. Elytral and pronotal measurements were used to quantify body size, and a mixed-effects model was used to test the effect of landscape complexity and local management on the body size, richness, and abundance of rove beetles. We found no effect of landscape composition or local management on body size, richness, or abundance of rove beetles. We hypothesize that the lack of landscape effects could be caused by less plasticity in functional traits in tropical versus temperate zones. Our results demonstrate that changes in land use and local management do not always lead to changes in the diversity and functional traits of predator communities.

Keywords: Functional traits, Landscape composition, Staphylinidae, Push–pull, Africa

Background

As global need for food and farmland increases, the way humans utilize the land is changing. Ecosystems worldwide are becoming increasingly homogenous due to increases in permanent pastureland and large-scale agriculture (Benton et al. 2003), and pastureland and arable crops together currently occupy 39% of the global terrestrial area (Alexander et al. 2015). Land use change has

been identified as a main driver of arthropod biodiversity loss worldwide (Sánchez-Bayo and Wyckhuys 2019) negatively affecting community assemblages (Tscharrntke et al. 2005; Gámez-Virués et al. 2015), and the ecosystem services they provide (Bianchi et al. 2006; Dainese et al. 2019; Grab et al. 2019). One important ecosystem service in agricultural systems is biological control. Biological control has been quantified as providing benefits valued as \$572/ha globally and at \$5.5 billion in the U.S. (Naranjo et al. 2015). Its promotion can reduce pesticide application by 70% and increase yields by 5% (Gurr et al. 2016). In agroecosystems, predation by natural enemies such as

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beetles is important for keeping pest pressure below economic injury levels (Letourneau et al. 2009; Rusch et al. 2015). Land use change and agricultural intensification is also known to affect natural enemies and biological control (Chaplin-Kramer et al. 2011; Veres et al. 2013; Zhao et al. 2015; Rusch et al. 2016). In general, (semi)natural habitats have been hypothesized to provide more floral resources, habitat refuges, protection from pesticides and alternate prey to sustain natural enemy populations (Geiger et al. 2010; Haan et al. 2019). Therefore, it is not surprising to find that landscapes dominated by agriculture have decreased richness and abundance of natural enemies (Dainese et al. 2019; Chaplin-Kramer et al. 2011; Veres et al. 2013) and less effective biological control (Dainese et al. 2019; Zhao et al. 2015).

The composition of the landscape is important not only due to its direct effect on natural enemy diversity and abundance, but also due to its potential interaction with local management strategies (Tscharrntke et al. 2005; Batáry et al. 2011). One such strategy is the push–pull system developed by the International Centre of Insect Physiology and Ecology (*icipe*) in Kenya to control stem-borers (Cook et al. 2007). In Kenya, lepidopteran stem-borer pests frequently attack small maize fields—one of the main staple crops—causing as much as 88% yield loss during the worst infestations (Midega et al. 2015). In response to the devastation caused by stem-borers, an integrated cropping system known as push–pull was implemented in the late 1990's. It consists of a maize field intercropped with *Desmodium* which acts as a deterrent (push) and surrounded by a border of Napier grass or *Brachiaria* sp. which act as attractant plants (pull). Push–pull farming has been successful in increasing yield and reducing stem-borer damage and has even remained effective in the presence of the recent invasion by fall armyworm (Midega et al. 2017). Push–pull fields also have increased plant diversity and higher percent ground cover which has been shown to benefit natural enemy populations (Rivers et al. 2016), and specifically increase the abundance of generalist predators (Kebede et al. 2018).

Studies and meta-analyses have shown a strong interaction between farm management and the surrounding landscape (Grab et al. 2019; Batáry et al. 2011; Poveda et al. 2019; Perez-Alvarez et al. 2019). A 2011 meta-analysis by Batáry et al. demonstrated that local agricultural management schemes such as flower strips and beetle banks were more effective at increasing biodiversity in simplified landscapes. This is because a farm surrounded by a high percentage of natural or semi-natural area (>20%) is likely already experiencing the ecological benefits of higher arthropod biodiversity, and so follows a law of diminishing returns in regard to human-implemented

increases in plant diversity (Batáry et al. 2011). However, most of this research comes from temperate regions, and data on natural enemies in tropical regions, particularly Sub-Saharan Africa, are largely lacking (but see (Midega et al. 2014; Mailafiya 2015; Ndakidemi et al. 2016; Stein et al. 2018)). Given that most of this work has been performed in temperate regions, we wanted to investigate if this hypothesis of landscape interactions with local management practices holds true for the push–pull maize cropping system in Kenya.

Furthermore, it is not just the abundance and diversity of natural enemies that is affected by land use change. Functional traits such as body size have also been shown to be affected by a decrease in the proportion of natural area (Perez-Alvarez et al. 2021). Functional traits are physical traits of organisms that have high variability and low heritability and can be influenced by environmental factors such as resource availability. They are advantageous for thinking about how organisms respond to changes in the environment in a way that directly impacts ecosystem functioning (Poff et al. 2006). Body size is a useful functional trait due to its variability and elastic response to resource availability (Gámez-Virués et al. 2015; Rusch et al. 2015; Perez-Alvarez et al. 2021; Renauld et al. 2016) and its ease for measurement. Functional traits can vary at the interspecific and also at the intraspecific level. For example, Gaméz-Virués et al. (2015) found interspecific variation where arthropod body size decreases with increasing proportion of natural area, a result supported by a recent study by Perez-Alvarez et al. (2021) on Carabidae. Body size can also be used to predict pest control in generalist predators, as demonstrated by Rusch et al. (2015). In generalist predators such as Carabidae, an increase in the body size of the community is positively related to predation rates in agroecosystems due to the increased abundance of a few larger-bodied species and the decrease of many smaller species (Perez-Alvarez et al. 2021).

We decided to study the effect of land use change and local management on functional traits in rove beetles (Coleoptera: Staphylinidae), both at the community level and for the most single abundant genus, given that this is a highly diverse group containing many generalist predators (Irmiler et al. 2018), and its relatively high abundance in tropical systems. In comparison with Carabidae (Perez-Alvarez et al. 2021; Kotze and O'Hara 2003), there is a distinct lack of literature pertaining to body size in Staphylinidae (but see (Rusch et al. 2014)). In addition, a recent meta-analysis found that out of 133 publications studying rove beetles, only 10% were done in the Oriental, Australian and Afrotropical regions combined, making this study unique in its biogeographical context (Méndez-Rojas et al. 2021). A

previous study has found no effect of landscape context on the diversity of staphylinids (Clough et al. 2007), but this was somewhat contradicted by recent findings by Méndez-Rojas et al. 2021, who found that richness decreased in agricultural landscapes, but not in urban areas. Based on previous research stating an effect of landscape composition on body size, we predict that landscapes with a low percentage of natural area will have generalist predator communities (Staphylinidae) with larger body sizes both at the community level and for individual species within the community. We also hypothesize that landscapes with a low percentage of natural area will have lower species richness and lower predator abundance, building on the findings of Perez-Alvarez et al. 2021. Based on the hypothesis that landscape can impact the efficacy of agri-environmental management methods (Batáry et al. 2011), the goal of our study was to investigate the single and combined effects of push-pull local management and landscape composition on body size, abundance, and richness of rove beetles in a Kenyan maize agroecosystem.

Methods

Site selection and landscape characteristics:

In 2018, 19 sites were selected in four districts in Kenya: Homa Bay, Bondo, Lambwe, and Rachuonyo (Fig. 1). The land cover surrounding each farm at a 250 m, 500 m, 750 m, and 1 km radius was classified as agricultural, semi-natural, developed, or open water using QGIS 3.4.12 (QGIS Development Team 2019) and Google Earth imagery from 2017 or 2018 (Google Earth, 2018). Landscape complexity was quantified as the percentage of natural area out of the total land area. Sites varied along a gradient of landscape complexity from 2.9% natural area to 25.3% natural area (mean 10.4% ± 6.5%). All farms were separated a minimum of 2 km from all other sites used in the study, with the exception of two farms that were approximately 400 m apart from each other. Each site had one control and one push-pull field that were located less than 30 m to one another.

All fields were predominantly maize, with occasional intercrops of groundnuts (*Apios americana*), beans (*Lablab purpureus*), cassava (*Manihot esculenta*) and greengrams (*Vigna radiata*). Control fields and push-pull

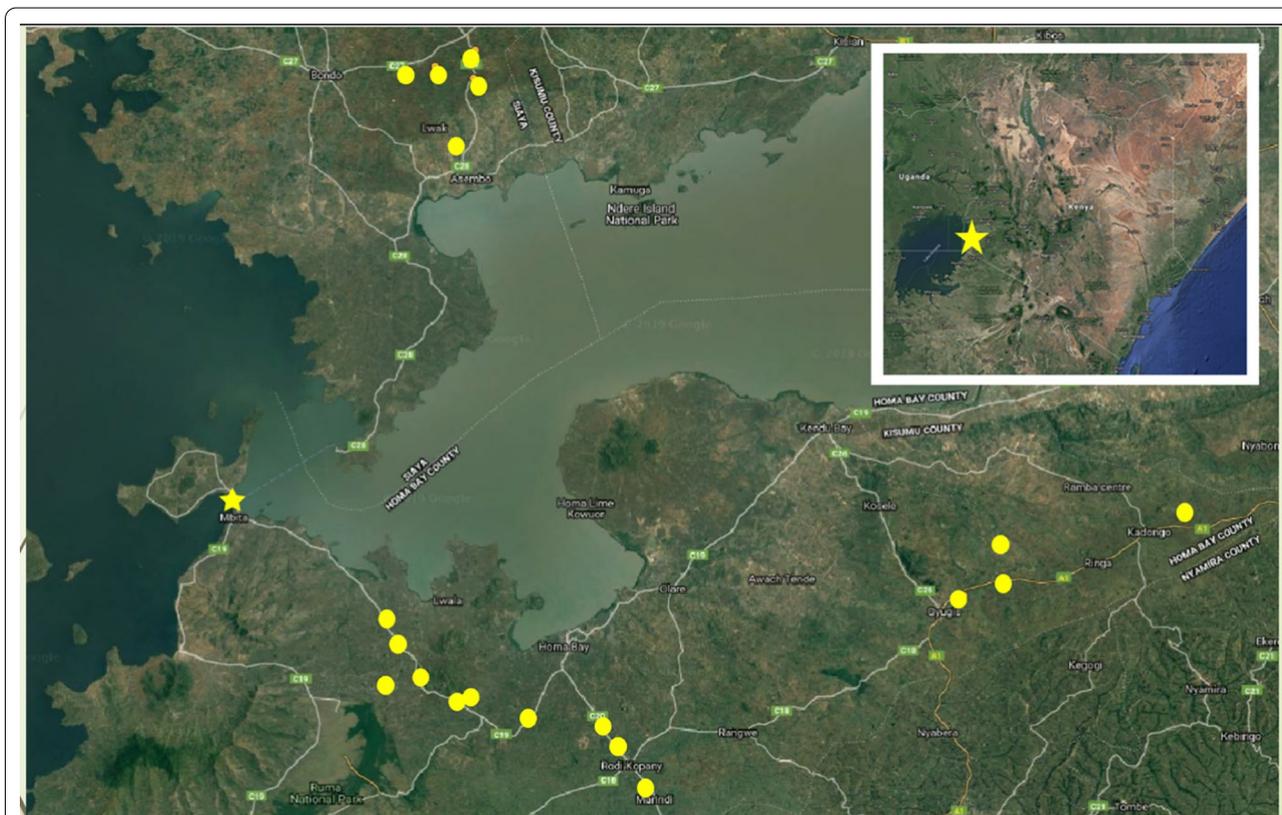


Fig. 1 Map showing the locations of the study sites (yellow dots). The body of water in the center of the map is a portion of the northeastern corner of Lake Victoria

fields were located on the same farm, managed by the same farmer, and at 17 out of the 19 farms they shared one border. Push–pull fields were intercropped with *Desmodium sp.* and surrounded by a border of either Napier grass (*Pennisetum purpureum*) (4/19) or signal-grass (*Brachiaria cv Mulato-II*) (15/19). The fields were planted at the beginning of the long rains season (February–April) by the farmers using their conventional planting practices for control fields and following the guidance of our collaborators at *icipa* for the push–pull fields.

Specimen collection and measurement

Specimens were collected twice. The first time while maize was in the tasseling stage between May 15 and June 7 2018 and the second time while ears were developing on the plants between June 12 and June 27 2018. Collection was done with pitfall traps and sweep net sampling. Five pitfall traps consisting of a standard SOLO brand 473 ml cup with approximately 100 ml of soapy water were placed near the four corners and in the center of each field and left open for 24 h during both sampling periods. Each sampling period also included a sweep net sample consisting of 25 sweeps taken between two rows of maize near the middle of the field for both the control and the push pull sites. Samples were stored in 70% ethanol. In the second sampling period only, a ten-minute transect walk was performed, in addition to the pitfall traps and the sweep netting, during which all arthropods that could be collected by hand from maize plants were sampled. After conducting preliminary abundance measurements, we found that rove beetles (Staphylinidae) were abundant in the system when compared to other putative predator taxa. Of 3519 putative predators, ants (Formicidae) accounted for 63% of specimens, and are outside of the scope of this paper. Of the remaining 1290 non-ant specimens, the most abundant groups included spiders (38%), parasitoid wasps (19%), Staphylinidae (10%), Coccinellidae (6%), and Dermaptera (4%). Spiders may predate on eggs occasionally but are generally not considered important egg predators and based on rearing of eggs collected from the field, egg parasitism was

extremely rare (Luttermoser et al. (in prep), unpublished data).

Due to a lack of relevant literature on measuring body size in Staphylinidae and Histeridae having similarly truncate elytra, our method was based on the work of Stoffolano & Geden (1987) on Histeridae (Stoffolano and Geden 1987). To measure body size, ten initial measurements were performed on 28 specimens belonging to the *Paederus* genus. The measurements were: pronotal width at the head, maximum pronotal width, right elytral width at anterior end, maximum right elytral length, and the diagonal length of the right elytron from inner left (anterior) to outer right (posterior) points, head width across eyes, maximum pronotal length, and the lengths of the hind femora and tibiae. We selected the traits with the highest variance with the expectation that these traits would be most likely to reflect any variation due to local management or landscape composition (Table 1).

From this analysis, elytra length, elytra diagonal, and maximum pronotal length exhibited the highest variance and were selected to measure on the remaining specimens. Diagonal elytral length was measured from the anterior left corner of the elytron to the posterior right corner in direct dorsal view. Maximum elytral length was measured from the anterior median to posterior median point. Maximum pronotal length was measured from the anterior medial to posterior medial point (Fig. 2). Measurements were taken using an Olympus SZX 10 stereo microscope and DP22 Microscope Digital Camera. Olympus cellSens Standard 1.16 software was used to measure beetles to the nearest 0.01 mm. Specimens were sorted to morphospecies based on observable characteristics such as number and shape of flagellomeres, shape of pronotum, size, and coloration. 13 morphospecies were identified to subfamily based on Ferro et al. 2015. Vouchers were deposited in the Cornell University Insect Collection, CUIC #000,002,452–#00,002,482.

Statistical analysis

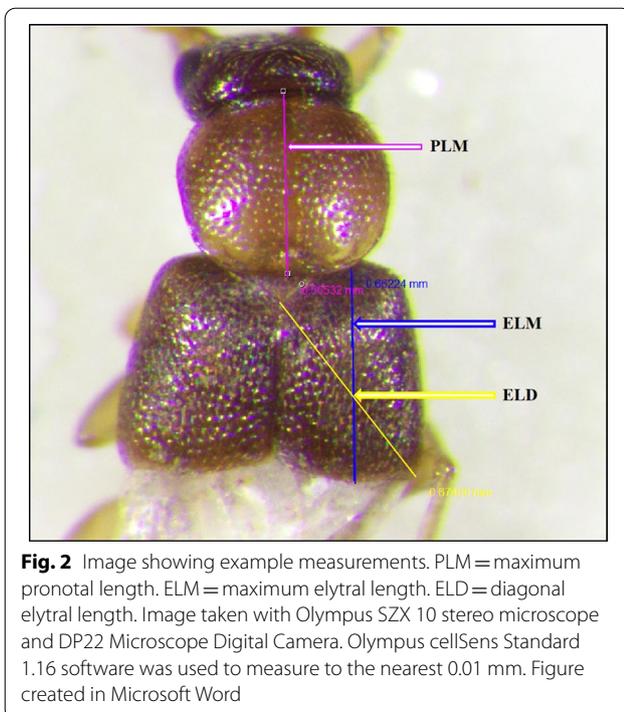
We used a mixed-effects model with farm ID as a random effect to test for the effect of local management (control vs push–pull), landscape complexity and their interaction on body size, richness, and abundance. We

Table 1 Means and variance for preliminary body size measurements

Trait	HW	PWH	PWM	PLM	EWA	ELM	ELD	HF	HT
Mean (mm)	1.165	0.4904	0.9779	1.239	0.6186	1.797	1.774	1.373	1.635
Variance	0.0030	0.0009	0.0030	0.0065	0.0033	0.0134	0.0151	0.0048	0.0063

All measurements taken on right side of specimen

HW head width, PWH pronotal width at head, PWM maximum pronotal width, PLM maximum pronotal length, EWA anterior elytral length, ELM maximum elytral length, ELD diagonal elytral length, HF hind femur, HT hind tibia



analyzed effects across all morphospecies, and for the genus *Paederus* specifically. *Paederus* was abundant across our sites (29 of 125 total specimens, or 23% of all specimens) and can be easily identified to genus.

We conducted separate analyses for all morphospecies and *Paederus* specifically to test whether the variation in body size was due to community variation or intraspecific variation within the single most numerous genus. We then ran a linear mixed model to test effects of landscape at the 250 m, 500 m, and 1 km scale using both community-level and *Paederus*-specific variation data to determine how landscape was influencing traits in the community. Data were analyzed in R-Studio, ver. 3.5.2 (R Core Team 2019) using packages *lme4* (Bates et al. 2015) and *nlme* (Pinheiro et al. 2021).

Results

We found a total of 125 specimens of 13 Staphylinidae morphospecies. 3 out of 19 farms had no staphylinids on either visit. The subfamilies identified were Paederinae, Staphylininae, Aleocharinae, Tachyporinae, Oxytelinae, Osoriinae, and Omaliinae. We found that the percentage of natural area did not significantly affect body size both within *Paederus* and at the family level (Table 2). Additionally, local management (push-pull vs control) did not have a significant effect on body size (Table 2). We also found no significant effect of the interaction between landscape and local management on body size within *Paederus* and at the family level (Table 2). Additionally, we found the percentage of natural area, local management and their interaction had

Table 2 Summary statistics for mixed-effects model fit by maximum likelihood for body size

Dependent	Predictor	Estimate	df	t-value	p-value
Pronotal length <i>Paederus</i>	% Natural area	- 0.552	12	- 1.135	0.279
	Treatment	- 0.068	2	- 0.851	0.484
	Trt*Natural area	0.514	2	0.893	0.466
Pronotal length all species	% Natural area	0.723	16	0.735	0.473
	Treatment	0.051	21	0.321	0.751
	Trt*Natural area	0.538	21	0.435	0.668
Elytral length <i>Paederus</i>	% Natural area	- 0.297	12	- 0.460	0.654
	Treatment	- 0.133	2	- 1.241	0.340
	Trt*Natural area	1.072	2	1.398	0.297
Elytral length All species	% Natural area	- 0.333	16	- 0.240	0.814
	Treatment	- 0.216	21	- 0.893	0.382
	Trt*Natural area	2.925	21	1.550	0.136
Diagonal elytral length <i>Paederus</i>	% Natural area	- 0.117	12	- 0.161	0.875
	Treatment	- 0.091	2	- 0.755	0.529
	Trt*Natural area	0.700	2	0.815	0.501
Diagonal elytral length All species	% Natural area	- 0.491	16	- 0.381	0.708
	Treatment	- 0.206	21	- 0.910	0.373
	Trt*Natural area	3.194	21	1.806	0.085

Values are given for all species as well as within the genus *Paederus*. Trt = treatment which refers to local management (push-pull vs control).

Table 3 Summary statistics for mixed-effects model fit by maximum likelihood for abundance and richness

Dependent	Predictor	Estimate	df	t-value	p-value
Abundance <i>Paederus</i>	% Natural area	0.845	17	0.415	0.683
	Treatment	0.232	55	0.658	0.514
	Trt*Natural area	1.318	55	0.458	0.649
Abundance All species	% Natural area	3.482	17	0.606	0.553
	Treatment	0.252	55	0.253	0.801
	Trt*Natural area	0.107	55	0.013	0.990
Richness All species	% Natural area	3.028	17	0.925	0.368
	Treatment	0.552	55	0.974	0.334
	Trt*Natural Area	-3.298	55	-0.712	0.480

Values are given for all species as well as within the genus *Paederus*

Trt = treatment which refers to local management (push-pull vs control)

no effect on abundance or richness at the morphospecies level (Table 3).

Discussion

Initially we predicted that an increase in the percentage of natural area would increase the richness and abundance of staphylinids but decrease the average body size. We also predicted that compared to a control field, a push-pull field would have higher Staphylinidae richness and abundance, and that this effect of push-pull would be stronger in a landscape with a lower proportion of natural area. Contrary to our predictions, we found no effect of proportion of natural area on body size, richness, or abundance. Additionally, we also did not find any interaction between landscape composition and push-pull and its effects on richness, abundance, or body size. Although our sample size can be considered relatively small, we have seen significant results in other studies with smaller sample sizes (Renauld et al. 2015), showing that the sample size of 112 individuals across 16 sites could still be rendering significant effects if those effects were strong. A larger sample size may have rendered other results, but given that the significance was so low, we trust that staphylinids do not vary as significantly. Moreover, staphylinids were a significant proportion of our non-ant predators, and we felt they were a potentially important predator group in our system and deserved to be analyzed.

Despite considerable evidence showing natural enemies respond to changes in landscape composition (Gámez-Virués et al. 2015; Chaplin-Kramer et al. 2011; Veres et al. 2013; Perez-Alvarez et al. 2021; Palmu et al. 2014), neither richness nor abundance of Staphylinidae changed with an increase in the percentage of natural area. Other studies have also found that staphylinids do not exhibit a consistent response to agricultural intensification (Rusch

et al. 2014; Méndez-Rojas et al. 2021; Palmu et al. 2014), and Tschardt et al. (2016) reviewed the mechanisms of why natural habitats can fail to support natural enemies, showing that positive effects of natural habitats on natural enemies and biological control are not always to be expected (Tschardt et al. 2016). Although there are many mechanisms that could be responsible for the lack of landscape and local effects on Staphylinidae richness and abundance, our results suggests that the Staphylinidae community does not seem to be affected by these particular local practices and by the land-use change seen in the area of study, as will be discussed below.

Our result for body size contradicts the work of Gámez-Virués et al. (2015), who suggested that landscape simplification results in larger body size across arthropod assemblages. Possible explanations could be that Staphylinidae are more robust, less plastic, and are able to withstand the negative effects of conventional farming and agricultural intensification. Although the existing literature has found that staphylinid assemblages tend to be negatively affected by anthropogenic disturbance (Caballero et al. 2009; Martins et al. 2013) this response is highly variable among species (Caballero et al. 2009; Work et al. 2013). It is also possible that our landscape gradient is not extreme enough to detect a measurable difference. Percent natural area in our study ranged from 2.9 to 25.3%. Still, studies in the same region on parasitoids have shown that even smaller gradients in landscape composition can have an effect on biological control (Midega et al. 2014), and differences in functional traits between predators and parasitoids can be one of the reasons those different responses are detected. It may be that staphylinids in our system do not experience extreme enough anthropogenic disturbance to have a pronounced effect on either body size or community composition, or it may also be that the composition of Staphylinidae does not show a unified response to simplification, but individual taxa may respond differently. It is surprising that we did not find higher staphylinid abundance in the push-pull fields, given that rove beetles are known to be active on the surface and benefit from diverse ground cover environments due to the increase in decaying plant matter (see Ref. Rivers et al. 2016). Additionally, certain specimens (*Paederus*) were hand collected from maize, while the rest were caught in pitfall traps. This suggests a possible spatial stratification in the staphylinid assemblage, which may also be contributing to the non-unified response to landscape simplification.

The local management of push-pull also did not affect diversity measures or body size. Although somewhat unexpected, it is not completely surprising since the push-pull and conventional farm treatments are

normally adjacent to each other. This proximity of the two management practices potentially also mitigates the effects of landscape simplification. Previous research has shown beetle banks and flower strips to be highly effective at conserving natural enemies (MacLeod et al. 2004), and research by Collins et al. (2002) demonstrated that predation increases in proximity to beetle banks (Collins et al. 2002). The configuration of the push–pull and control fields as directly adjacent to or very near each other may result in a beetle bank effect where arthropod predators and prey from the conventional system can find refuge in the Napier or *Brachiaria* grass that borders the push–pull fields.

This is encouraging information for Kenyan farmers because it suggests that farmers may be able to experience the pest control benefits of push–pull without implementing it across all fields, as suggested by long term analysis of the data (Luttermoser et al. in prep). This could potentially save farmers both time and money while still effectively controlling stemborer pests and providing the benefits of agri-environmental management not just to the managed, but also to the adjacent fields.

Another hypothesis for the lack of effect from land use change and local management on rove beetle communities, is that this study was conducted in the tropics. Most of the work investigating landscape effects on arthropod communities has been done in temperate regions (Rusch et al. 2015; Chaplin-Kramer et al. 2011). However, it is known that the diversity and number of interactions increases towards the tropics (Hargreaves et al. 2019). Maybe this higher diversity makes tropical systems more resilient to disturbance and also makes communities of arthropods more resilient. Although we do not have enough evidence in this paper or the current literature to test this hypothesis, we propose that a meta-analysis would be a useful way to test this hypothesis more broadly, as soon as enough data are available to test it. It would be informative to conduct bioassays with *Paederus* species and *Spodoptera* eggs to assess their biocontrol potential. We know that *Paederus* was a highly abundant genus in our samples, and were hand collected from maize plants. Moreover, both larvae and adults of this genus are known to be generalist predators (Frank and Paederus 1987), so there is a possibility for egg predation in the field. We also suggest further studies on functional traits and cropping systems in tropical regions on other morphologically and taxonomically diverse groups such as Diptera, Hymenoptera, and other Coleoptera. These groups are potentially providing important ecosystem services on farms, and more research should investigate how their functional traits may vary with both landscape complexity as well as local farm management.

Conclusions

Our results show that in tropical agroecosystems local and landscape effects do not affect rove beetle communities in terms of richness, abundance, and body size. Although this does not match predictions generated from temperate regions, we think that this study along with others from the tropics could be the clue to better understand latitudinal gradients of biodiversity and the impacts that land-use change has on them.

The insert shows Kenya and the location of the study sites is shown by the white box.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s43170-022-00119-1>.

Additional file 1: Full_staphylinid_datasetR1.

Additional file 2: Individual_measurementsR1.

Additional file 3: Natural_area_dataR1.

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Author contributions

KP conceived of the study design. TJL collected the samples. NGD collected the data. NGD analyzed the data with input from KP and TJL. NGD wrote the manuscript, with edits from TJL and KP. All authors reviewed and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and its Additional files 1, 2 and 3.

Declarations

Competing interests

All authors certify that they have no competing interests.

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References

- Alexander P, Rounsevell MDA, Dislich C, Dodson JR, Engström K, Moran D. Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. *Glob Environ Change*. 2015;35:138–47.
- Batáry P, Báldi A, Kleijn D, Tscharntke T. Landscape-moderated biodiversity effects of agri-environmental management: A meta-analysis. *Proc Roy Soc B: Biol Sci*. 2011;278(1713):1894–902.

- Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Soft.* 2015;67(1).
- Benton TG, Vickery JA, Wilson JD. Farmland biodiversity: is habitat heterogeneity the key? *Trends Ecol Evol.* 2003;18(4):182–8.
- Bianchi FJJA, Booij CJH, Tscharntke T. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proc Biol Sci.* 2006 Jul;273(1595):1715–27.
- Caballero U, León-Cortés JL, Morón-Ríos A. Response of rove beetles (Staphylinidae) to various habitat types and change in Southern Mexico. *J Insect Conserv.* 2009;13(1):67–75.
- Chaplin-Kramer R, O'Rourke ME, Blitzer EJ, Kremen C. A meta-analysis of crop pest and natural enemy response to landscape complexity: Pest and natural enemy response to landscape complexity. *Ecol Lett.* 2011;14(9):922–32. <https://doi.org/10.1111/j.1461-0248.2011.01642.x>.
- Clough Y, Kruess A, Tscharntke T. Organic versus conventional arable farming systems: functional grouping helps understand staphylinid response. *Agric Ecosyst Environ.* 2007;118(1–4):285–90.
- Collins KL, Boatman ND, Wilcox A, Holland JM, Chaney K. Influence of beetle banks on cereal aphid predation in winter wheat. *Agric Ecosyst Environ.* 2002;93(1–3):337–50.
- Cook SM, Khan ZR, Pickett JA. The use of push-pull strategies in integrated pest management. *Annu Rev Entomol.* 2007;52(1):375–400. <https://doi.org/10.1146/annurev.ento.52.110405.091407>.
- Dainese M, Martin EA, Aizen MA, Albrecht M, Bartomeus I, Bommarco R, et al. A global synthesis reveals biodiversity-mediated benefits for crop production. *Sci Adv.* 2019;5(10):eaax0121. <https://doi.org/10.1126/sciadv.aax0121>.
- Frank JH, Kanamitsu K. Paederus, *Sensu Lato* (Coleoptera: Staphylinidae): natural history and medical importance. *J Med Entomol.* 1987;24(2):155–91. <https://doi.org/10.1093/jmedent/24.2.155>.
- Gómez-Virués S, Perović DJ, Gossner MM, Börschig C, Blüthgen N, de Jong H, et al. Landscape simplification filters species traits and drives biotic homogenization. *Nature Commun.* 2015;6(1):8568.
- Geiger F, Bengtsson J, Berendse F, Weisser WW, Emmerson M, Morales MB, et al. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Appl Ecol.* 2010;11(2):97–105.
- Grab H, Branstetter MG, Amon N, Urban-Mead KR, Park MG, Gibbs J, et al. Agriculturally dominated landscapes reduce bee phylogenetic diversity and pollination services. *Science.* 2019;363(6424):282–4. <https://doi.org/10.1126/science.aat6016>.
- Gurr GM, Lu Z, Zheng X, Xu H, Zhu P, Chen G, et al. Multi-country evidence that crop diversification promotes ecological intensification of agriculture. *Nat Plants.* 2016;2(3):16014.
- Haan NL, Zhang Y, Landis DA. Predicting landscape configuration effects on agricultural pest suppression. *Trends Ecol Evol.* 2019. <https://doi.org/10.1016/j.tree.2019.10.003>.
- Hargreaves AL, Suárez E, Mehlreter K, Myers-Smith I, Vanderplank SE, Slinn HL, et al. Seed predation increases from the Arctic to the Equator and from high to low elevations. *Sci Adv.* 2019;5(2):eaau4403. <https://doi.org/10.1126/sciadv.aau4403>.
- Irmiler U, Klimaszewski J, Betz O. Introduction to the Biology of Rove Beetles. In: Betz O, Irmiler U, Klimaszewski J, editors. *Biology of Rove Beetles (Staphylinidae)*. Cham: Springer International Publishing; 2018. p. 1–4. <https://doi.org/10.1007/978-3-319-70257-5>.
- Kebede Y, Baudron F, Bianchi F, Tittonell P. Unpacking the push-pull system: assessing the contribution of companion crops along a gradient of landscape complexity. *Agric Ecosyst Environ.* 2018;268:115–23.
- Kotze DJ, O'Hara RB. Species decline—but why? Explanations of carabid beetle (Coleoptera, Carabidae) declines in Europe. *Oecologia.* 2003;135(1):138–48. <https://doi.org/10.1007/s00442-002-1174-3>.
- Létourneau DK, Jedlicka JA, Bothwell SG, Moreno CR. Effects of natural enemy biodiversity on the suppression of arthropod herbivores in terrestrial ecosystems. *Ann Rev Ecol Syst.* 2009;40(1):573–92. <https://doi.org/10.1146/annurev.ecolsys.110308.120320>.
- MacLeod A, Wratten SD, Sotherton NW, Thomas MB. "Beetle banks" as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat. *Agric For Entomol.* 2004;6(2):147–54. <https://doi.org/10.1111/j.1461-9563.2004.00215.x>
- Mailafiya DM. Agrobiodiversity for biological pest control in Sub-Saharan Africa. In: Lichtfouse E (Ed) *Sustainable agriculture reviews*. Cham: Springer International Publishing; vol 18. 2015. p. 107–43. https://doi.org/10.1007/978-3-319-21629-4_4.
- Martins ICF, Cividanes FJ, Ide S, Haddad GQ. Diversity and habitat preferences of Carabidae and Staphylinidae (Coleoptera) in two agroecosystems. *Bragantia.* 2013;71(4):471–80.
- Méndez-Rojas DM, Cultid-Medina C, Escobar F. Influence of land use change on rove beetle diversity: A systematic review and global meta-analysis of a mega-diverse insect group. *Ecol Indicators.* 2021;122:107239.
- Midega CAO, Bruce TJA, Pickett JA, Pittchar JO, Murage A, Khan ZR. Climate-adapted companion cropping increases agricultural productivity in East Africa. *Field Crops Res.* 2015;180:118–25. <https://doi.org/10.1016/j.fcr.2015.05.022>.
- Midega CAO, Pittchar JO, Pickett JA, Hailu GW, Khan ZR. A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J E Smith), in maize in East Africa. *Crop Prot.* 2018;105:10–5. <https://doi.org/10.1016/j.cropro.2017.11.003>.
- Midega CAO, Jonsson M, Khan ZR, Ekobom B. Effects of landscape complexity and habitat management on stemborer colonization, parasitism and damage to maize. *Agric Ecosyst Environ.* 2014;188:289–93.
- Naranjo SE, Ellsworth PC, Frisvold GB. Economic Value of Biological Control in Integrated Pest Management of Managed Plant Systems. *Annu Rev Entomol [Internet].* 2015;60(1):621–45. <https://doi.org/10.1146/annurev-ento-010814-021005>.
- Ndakidemi B, Mtei K, Ndakidemi PA. The potential of common beneficial insects and strategies for maintaining them in bean fields of Sub Saharan Africa. *AJPS.* 2016;07(03):425–36. <https://doi.org/10.4236/ajps.2016.73036>.
- Palmu E, Ekroos J, Hanson HI, Smith HG, Hedlund K. Landscape-scale crop diversity interacts with local management to determine ground beetle diversity. *Basic Appl Ecol.* 2014;15(3):241–9.
- Perez-Alvarez R, Nault BA, Poveda K. Effectiveness of augmentative biological control depends on landscape context. *Sci Rep.* 2019;9(1):8664.
- Perez-Alvarez R, Grab H, Polyakov A, Poveda K. Landscape composition mediates the relationship between predator body size and pest control. *Ecol Appl.* 2021. <https://doi.org/10.1002/eap.2365>.
- Pinheiro J, Bates D, DebRoy S, Sarkar D. nlme: linear and nonlinear mixed effects models. 2021. <https://CRAN.R-project.org/package=nlme>. Accessed 8 Aug 2021.
- Poff NL, Olden JD, Vieira NKM, Finn DS, Simmons MP, Kondratieff BC. Functional trait niches of North American lotic insects: traits-based ecological applications in light of phylogenetic relationships. *J North Am Benthol Soc.* 2006;25(4):730–55. [https://doi.org/10.1899/0887/3593\(2006\)025\[0730:FTNONA\]2.0.CO;2](https://doi.org/10.1899/0887/3593(2006)025[0730:FTNONA]2.0.CO;2).
- Poveda K, Díaz MF, Espinosa S, Obregon D, Ramirez A. Landscape complexity and elevation affect the effectiveness of a local pest-management practice. *Glob Ecol Conserv.* 2019;20:e00763.
- Renauld M, Hutchinson A, Loeb G, Poveda K, Connelly H. Size in a native ground-nesting bee. *PLoS ONE.* 2016. <https://doi.org/10.1371/journal.pone.0150946>.
- Rivers A, Barbercheck M, Govaerts B, Verhulst N. Conservation agriculture affects arthropod community composition in a rainfed maize-wheat system in central Mexico. *Appl Soil Ecol.* 2016;100:81–90.
- Rusch A, Birkhofer K, Bommarco R, Smith HG, Ekobom B. Predator body sizes and habitat preferences predict predation rates in an agroecosystem. *Basic Appl Ecol.* 2015;16(3):250–9. <https://doi.org/10.1016/j.baee.2015.02.003>.
- Rusch A, Birkhofer K, Bommarco R, Smith HG, Ekobom B. Management intensity at field and landscape levels affects the structure of generalist predator communities. *Oecologia.* 2014;175(3):971–83. <https://doi.org/10.1007/s00442-014-2949-z>.
- Rusch A, Chaplin-Kramer R, Gardiner MM, Hawro V, Holland J, Landis D, et al. Agricultural landscape simplification reduces natural pest control: a quantitative synthesis. *Agric Ecosyst Environ.* 2016;221:198–204.
- Sánchez-Bayo F, Wyckhuys KAG. Worldwide decline of the entomofauna: a review of its drivers. *Biol Conserv.* 2019;232:8–27.
- Stein K, Stenchly K, Coulibaly D, Pauly A, Dimobe K, Steffan-Dewenter I, et al. Impact of human disturbance on bee pollinator communities in savanna and agricultural sites in Burkina Faso, West Africa. *Ecol Evol.* 2018;8(13):6827–38. <https://doi.org/10.1002/ece3.4197>.
- Stoffolano JG, Geden CJ. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops Pumilio* (Coleoptera:

- Histeridae) sex ratios, ovarian condition, and body size. *J Med Entomol.* 1987;24(2):212–20. <https://doi.org/10.1093/jmedent/24.2.212>.
- Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C. Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management. *Ecol Lett.* 2005;8(8):857–74.
- Tscharntke T, Karp DS, Chaplin-Kramer R, Batáry P, DeClerck F, Gratton C, et al. When natural habitat fails to enhance biological pest control—five hypotheses. *Biol Conserv.* 2016;204:449–58.
- Veres A, Petit S, Conord C, Lavigne C. Does landscape composition affect pest abundance and their control by natural enemies? A review. *Agric Ecosyst Environ.* 2013;166:110–7.
- Work TT, Klimaszewski J, Thiffault E, Bourdon C, Paré D, Bousquet Y, et al. Initial responses of rove and ground beetles (Coleoptera, Staphylinidae, Carabidae) to removal of logging residues following clearcut harvesting in the boreal forest of Quebec, Canada. *ZooKeys.* 2013;(258):31–52.
- Zhao ZH, Sandhu HS, Gao F, He DH. Shifts in natural enemy assemblages resulting from landscape simplification account for biocontrol loss in wheat fields. *Ecol Res.* 2015;30(3):493–8. <http://doi.org/10.1007/s11284-015-1245-7>.

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