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Beyond prime areas of nature protection in East Africa: conservation ecology of a narrowly distributed Kenyan endemic bird species

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Abstract Conflicts between human needs and nature conservation are exceptionally pronounced along rivers in tropical Kenya, where riparian ecosystems create important retreats for many endangered species, but also provide important ecosystem services for the local human population. This situation has led to a landscape mosaic consisting of dense thickets and agricultural plots. We assessed the occurrence of the Kenyan endemic riparian bird species Hindeś Babbler *Turdoides hindei* along three rivers in south-east Kenya. We analysed the landscape coverage within habitat circles of 220 m radius, which are occupied and unoccupied (the latter randomly selected along the rivers) by our targeted bird species. Based on these data we calculated habitat preferences and population structure of *T. hindei*. Our data reveal that its occurrence probability increased with coverage of thickets. Furthermore, geographic distances among local populations of *T. hindei* decreased with thicket coverage and vice versa. These data reveal the relevance of thicket coverage as a key factor for the occurrence of *T. hindei*, influencing its population structure. However, most of the thicket patches mapped along the three rivers are small and geographically isolated from each other. Further deforestation might lead to additional reduction of the population size and abundance of *T. hindei*, and may ultimately lead to local extinction of this, and other endangered species adapted on riparian thickets. This

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example underlines the need to extend nature conservation to areas being densely populated by humans—beyond prime areas of nature conservation in East Africa.

Keywords Effective habitat size · Riparian thicket · Habitat fragmentation · Invasive *Lantana camara* · Potential habitat size · *Turdoides hindei*

Introduction

Biodiversity is under highest threat in areas with high human demographic pressure, like in major parts of the tropics, where native habitats are rapidly transformed into agricultural land (Foley et al. 2005). Such ecosystems being strongly affected by anthropogenic activities are rivers of the dry lowland regions of East Africa, which are bordered by riparian forests. These ecosystems represent important habitats for many endangered species. Simultaneously, they also provide important ecosystem services for the local human population settling along these streams (Ahrends et al. 2010; Demos et al. 2014). Originally, such riparian forests have provided interconnected corridors throughout the dry lowland regions (Boahene 1998). However, most of them became transformed into agricultural land due to human population pressure. This habitat destruction is further enhanced by decreasing soil fertility and subsequent need of new land, and a rather weak conservation policy (Burgess et al. 2005; Pfeifer et al. 2012; Habel et al. 2015).

A representative species found in such highly degraded lowland riparian thickets is the Kenyan endemic Hindes' Babbler *Turdoides hindei* (Njoroge and Bennun 2000). This bird is a cooperative breeder, found mostly in small family groups (Njoroge et al. 1998; Shaw and Musina 2003). The specieś distribution range is restricted to central and south-east Kenya, dividing into five regionally distinct and small population clusters (Njoroge and Bennun 2000; Zimmerman et al. 2005; BirdLife International 2012; Shaw et al. 2013, 2014). Its habitat are dense riparian thickets (both, pristine vegetation and the invasive *Lantana camara*, Teucher et al. 2015) along rivers at higher altitudes like in the Aberdares around Nyeri, at the foothills of Mt. Kenya as Kianyaga and Meru; but also in the much drier and warmer lowland regions, like the semi-arid savannahs around Machakos and Kitui, or at intermediate altitude around Thika, Sagana and Oldonyo Sabuk region. Apart from riparian thickets, this bird can also be found in agricultural plots such as coffee plantations (JCH, personal observations around Nyeri). Fast transformation of pristine vegetation into agricultural land caused decreasing abundance of this species during the past 10 years (Njoroge and Bennun 2000; Zimmerman et al. 2005; BirdLife International 2012), with an approximate loss of more than 60 % of its original distribution (Shaw et al. 2013). Populations at the specieś south-eastern distribution margin like Machakos and Kitui (our study region) and eastwards are in particular assumed to suffer under recent habitat destruction (Shaw et al. 2013). Today, *T. hindei* is classified as "globally vulnerable" according the IUCN Red List criteria (BirdLife International 2012).

In this study we analysed the habitat preferences and occurrence probability of this bird species in a highly degraded mosaic consisting of riparian thickets and agricultural plots, along three rivers in south-east Kenya. These three selected rivers represent diverging levels of degradation: (i) Kalundu river provides still intact riparian thicket; (ii) the vegetation along Nzeeu river becomes dominated by the exotic invasive *L. camara*, and (iii) Ithiani river represents a worst-case scenario, with only few riparian thicket fragments left. We assessed the occurrence of *T. hindei* and analysed the land cover along these three rivers, and in particular within habitat circles being occupied and unoccupied by our targeted study species. Based on these data we test for potential effects of landscape structures (thicket and open agricultural land) and for potential effects of the distance among remaining thicket patches on the occurrence of *T. hindei*. This conceptual framework allows to evaluate the conservation value of riparian vegetation, and to delineate corridors of life in a poorly protected environment of East Africa. In the following we elaborate three research questions:

(i) Does land-use and the type of land cover influence the occurrence of *T. hindei*?
(ii) Which landscape parameters predominantly influence its population structure?
(iii) Which conservation strategies can be drawn from our findings?

Materials and methods

Study species

The Kenyan endemic bird species Hindeś Babbler *T. hindei* exists in family groups, ranging from some few to 10 individuals (JCH, own observations). The species is mainly found in dense vegetation, feeding on insects and foraging at the ground (Teucher et al. 2015). Larger distances among suitable habitat patches are bridged by flying; here, individuals move to an outstanding tree, keep contact by increasing volume of the contact call, and fly to an outstanding tree to the other thicket patch (JCH, own observations). Habitat quality (e.g. the level of habitat fragmentation) affects the population structure of *T. hindei*. Previous studies indicated a positive correlation between thicket coverage and the number of members per group (i.e. family size); furthermore, the size of territories increase with decreasing thicket coverage (Shaw and Musina 2003; Shaw et al. 2013). Thus, individuals persisting in highly degraded environments are assumed to have to forage more frequently among thicket remnants, which might lead to increasing predation pressure, or might have negative edge effects on the remaining habitat patches (reduced habitat quality).

Study region

We performed our study along three rivers, Ithiani, Kalundu and Nzeeu, all located south of the town of Kitui, south-eastern Kenya (Fig. 1). Land coverage bordering these three rivers represent diverging conditions: most of the vegetation along Ithiani river was cleared during the past, while Kalundu river is still lined by intact and dense pristine thicket (only slightly intermixed by the invasive *L. camara*); the vegetation along Nzeeu river is dominated by the invasive *L. camara*. This invasive plant species, originally from South America, settled in East Africa during the 1950s, and spread along most (mainly disturbed) ecosystems. Today, major parts of riparian vegetation of East Africa become dominated by this plant species, with detrimental effects on many species, like birds (Arrived et al. 2010). The study region is characterized by semi-arid climatic conditions, with 800–1000 mm precipitation during bi-annual rainy seasons in March-June and October-January. The annual mean temperature is 21 °C. The soil fertility is comparatively low and soils are predominantly acrisols, ferralsols and luvisols (Jaetzold et al. 2007). The human population increased rapidly in our study region, and almost doubled during the past 10 years (KNBS 2010). Most of the local people (97 %) in this region depend on subsistence agriculture (Kenya Open Data Initiative 2014). Agricultural activities are concentrated along the border of rivers because of the availability of ground water, fertile soil, wood for brick- and

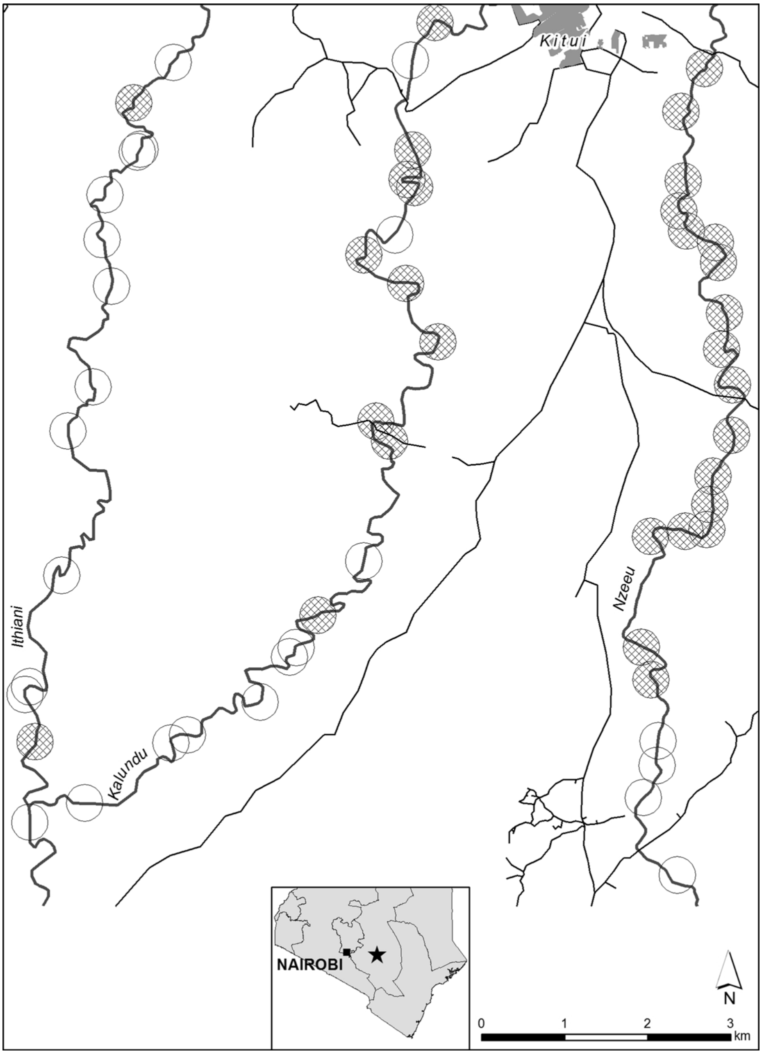

Fig. 1 Study area displaying the 55 study locations along the three rivers, Ithiani, Kalundu and Nzeeu (large map). *Circles* indicate the distribution of studied 220 m landscape *circles*, occupied by *Turdoides hindei* crosshatched circles, *unoccupied* white circles. The small map at the *bottom* shows the study location in Kenya, with our study region indicated by a star

charcoal production, and timber for house construction. The increasing need for land and resources creates a conflicting situation between usage and the preservation of habitats for endangered species (Teucher et al. 2015).

Data acquisition

In a first step we assessed the landscape structures in a 25 m buffer along both sides of the three rivers during March and August 2014. We used a Garmin GPSMap 60CSx GPS device and mapped the following land cover categories: pristine thicket, *L. camara*, mixed vegetation (combination of pristine thicket with *L. camara*), and open space (agriculture and fallow land).

In a second step we assessed the occurrence of *T. hindei* families for the same study region during March and August 2014. For the detection of local populations we played the alarm calls of *T. hindei*, which were previously recorded at Nzeeu river. This call was played each 100 m in the riverbed for 1 min with identical volume. When *T. hindei* individuals responded, we observed the family group for about 1 h, determining the number of individuals and measuring their exact geographic location with a GPS device (same as above). We performed this assessment of *T. hindei* occurrence six times (three times in March and three times in August 2014) under identical conditions to guarantee the detection of all existing local *T. hindei* family groups. Repeated observations of the same family group, identified by identical number of individuals and their exact geographic location, were merged afterwards and treated as the same family.

In a third step we calculated the mean habitat size of *T. hindei* according to previous data (Teucher et al. 2015). We calculated the mean territory size for single family groups (5.0 individuals per family on average—see results), based on the results found by Teucher et al. (2015). We used 15 ha (i.e. a circle of 220 m radius) as mean territory size per family group. We generated these landscape circles with the buffer function of QGIS vers. 2.2.0 (QGIS Development Team 2014). We set circles along the three rivers at points where *T. hindei* individuals were observed ($N = 31$). Unoccupied circles ($N = 25$) were randomly chosen along the three rivers using the 'random points along line' function in QGIS, and ensuring that there was no overlap with circles being occupied by *T. hindei*. For each landscape circle we assessed the following land cover categories, which were digitized as polygons and points using QGIS vers. 2.2.0 (QGIS Development Team 2014): (i) riverbed (area of the dried-up stream), (ii) thickets (both, pristine and *L. camara*), (iii) human settlement, (iv) open space (agriculture and fallow land), and (v) trees (as points). To calculate proportions of land cover categories we converted tree points into area information by calculating the mean coverage space (57.30 m^2) per tree in the study region based on a subsample of 1 % of all trees assessed in the area. Proportions of landscape coverage along the three rivers was calculated for each circle and visualized for each category with the program QGIS vers. 2.2.0 (QGIS Development Team 2014) (Fig. 1). For the landscape circles we calculated the relative abundance of each land cover category. Furthermore, we calculated the minimum distance to the closest landscape circle occupied by *T. hindei* to express the degree of population isolation of each family group assessed, and to calculate the occurrence probability depending on land coverage (thicket) and its impact on the geographic distance among local populations.

Statistics

Comparison of land cover composition among the 25 m buffers around the three rivers was tested using Kruskal–Wallis test. To test for potential differences in landscape composition of occupied and unoccupied circles, and for the size of the family groups between the three rivers we calculated a one-way analysis of variance (ANOVA) in case of normally distributed data or Kruskal–Wallis test in case of non-normality of the data. To avoid multicollinearity between the landscape variables, we performed a Spearman rank correlation according to non-normality of most of the landscape variables. In case of a significant correlation between variables, only the variable with the longer gradient length was selected for further analyses (all values are given in Supplementary Material S1). Variables with a gradient length shorter than 10 % of the potential gradient length were excluded from further analyses. Therefore, we modelled *T. hindei* presence or absence in relation to the thicket coverage, the distance to the closest *T. hindei* family, and two-way interaction using generalized linear models (GLMs) with a quasi-binomial distribution due to over dispersion. The data were analysed with R version 3.0.2 (R Core Team 2013).

Results

Landscape composition of the 25 m riparian buffer

The proportion of the four land cover categories differed significantly among the three rivers ($\chi^2 = 21.35$, $P < 0.001^{***}$, N = 584), with lowest vegetation cover found along Ithiani river (43.28 %, of which 19.43 % is still representing indigenous vegetation), intermediate vegetation cover along Nzeeu river (45.70 %, however dominated by *L. camara*), and highest vegetation cover along Kalundu river (61.60 %, of which 35.25 % is pristine vegetation). The mean length of thicket patches over all three rivers analysed was 133.52 ± 6.90 m, ranging from 9.72 to 1109.66 m; 80 % of the assessed thicket patches were <190 m. The mean geographic distance among thicket patches was 244.45 ± 13.46 m, ranging from 17.37 to 2021.49 m; geographic distances among thicket patches were >370 m for 80 % of the thickets assessed. The composition of land cover differed significantly between the two riversides of the three rivers ($\chi^2 = 144.79$, $P < 0.001^{***}$, N = 584).

Land cover in 220 m landscape circles

The means of the different land cover categories across all three rivers were as follows: 58.22 ± 2.27 % for open space (i.e. agriculture and fallow land), 32.50 ± 2.32 % for pristine and *L. camara* thicket, 0.18 ± 0.00 % settlements, 6.60 ± 0.44 % riverbed, and 2.49 ± 0.19 % trees (raw data for all landscape circles are given in Supplementary Material S2). The proportions of land cover among these categories differed significantly between circles being occupied and those not occupied by *T. hindei*.

We found significant differences of land coverage within landscape circles among the three rivers assessed; here, the proportion of settlements ($\chi^2 = 12.90$, d.f. = 2, P = 0.002), as well as the proportion of trees ($\chi^2 = 9.24$, d.f. = 2, $P < 0.001$) differed among the three rivers. However, there was no significant difference in landscape variables used for further analysis (thicket: $F_{2,\ 52} = 0.76$, P = 0.47; distance occupied: $\chi^2 = 5.91$, d.f. = 2, P = 0.05; distance unoccupied: $\chi^2 = 0.64$, d.f. = 2, P = 0.73). The geographic distance between of landscape circles and a neighbouring, closest landscape circle occupied by *T. hindei* was in mean 848.33 m ± 97.84 m, with distances ranging from 131.59 to 3318.49 m.

Occurrence probability of *Turdoides hindei*

Our bird observations revealed the existence of 31 family groups of *T. hindei* along the three rivers, with one family at the highly degraded Ithiani river, 10 families in the pristine riparian thickets along Kalundu river and 20 families along the *L. camara* thickets bordering Nzeeu river (Table 1). The family sizes ranged from 1 individual to 9 individuals, with a mean of 5.00 ± 0.39 individuals per family group (Table 1). Sizes of family groups

Table 1 Observed family groups of *Turdoides hindei* along the three rivers (Ithiani, Kalundu and Nzeeu)

River	N	Date
Ithiani	3	March 2014
Kalundu	5	August 2014
Kalundu	2	August 2014
Kalundu	9	August 2014
Kalundu	4	August 2014
Kalundu	3	August 2014
Kalundu	NA	March 2014
Kalundu	5	March 2014
Kalundu	9	March 2014
Kalundu	5	March 2014
Kalundu	3	March 2014
Nzeeu	3	August 2014
Nzeeu	4	August 2014
Nzeeu	3	August 2014
Nzeeu	6	August 2014
Nzeeu	7	August 2014
Nzeeu	5	August 2014
Nzeeu	7	August 2014
Nzeeu	9	August 2014
Nzeeu	1	August 2014
Nzeeu	4	March 2014
Nzeeu	7	March 2014
Nzeeu	8	March 2014
Nzeeu	4	March 2014
Nzeeu	5	March 2014
Nzeeu	6	March 2014
Nzeeu	6	March 2014
Nzeeu	3	March 2014
Nzeeu	5	March 2014
Nzeeu	4	March 2014
Nzeeu	NA	March 2014

Given are the number of individuals observed and the date of observations

did not significantly differ among the three rivers ($F_{2,\ 26} = 0.45$, $P = 0.64$). Increasing thicket coverage showed a positive effect on the probability of the occurrence of *T. hindei* (Estimate: 0.08 ± 0.04; $t_{51} = 2.04$; $P = 0.04$). Furthermore we found a significant interaction between thicket coverage and distance to the next *T. hindei* family (Estimate: -0.0001 ± 0.00; $t_{51} = -2.22$; $P = 0.03^{*}$), with increasing occurrence probability of *T. hindei* far from the next *T. hindei* family group when thicket coverage was low (<20 % proportion of thicket, Fig. 2a). The occurrence probability close to other family groups increased with higher thicket coverage, shown for landscape circles with more than 20 % thicket coverage (Fig. 2b, c), and with strongest effects for landscape circles with thicket coverage >45 % (Fig. 2d). Distance to the next T. *hindei* family alone had no significant effect on the occurrence probability (Estimate: 0.002 ± 0.001; $t_{51} = 1.42$; $P = 0.16$).

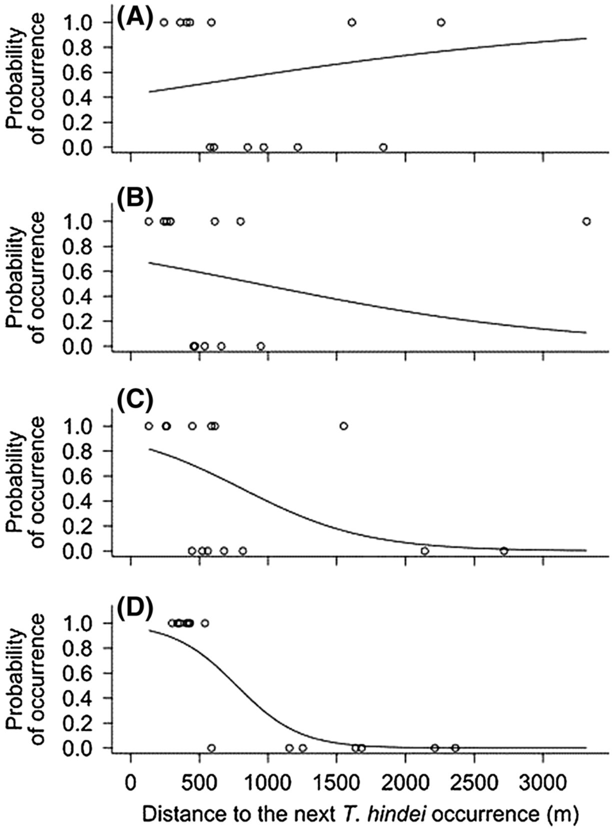

Fig. 2 Occurrence probability of *Turdoides hindei* depending on (i) the distance to closest *T. hindei* family and (ii) the proportion of thicket, including the following threshold values: 0–20 % (**a**); 20–30 % (**b**); 30–45 % (**c**); >45 % (**d**). Regression *lines* represent prediction *lines* from the generalized linear models (GLMs)

Discussion

Our data show that *T. hindei* exists in distinct family groups along the three studied rivers. The occurrences of *T. hindei* clustered, with high densities found at Nzeeu river (20 families), lower densities at Kalundu river (10 families), and only one single and isolated family found at Ithiani river. We found two main factors influencing the occurrence of the species and shaping its population structure. First, the specieś key habitat: dense pristine riparian or *L. camara* thicket. Second, increasing proportion of thicket cover is related with decreasing geographic distance (isolation) among families of *T. hindei*.

Riparian thickets: the key habitat resource

The occurrence probability of *T. hindei* is predicted to be higher in areas with high proportion of thicket. This result underlines the relevance of dense thickets for this (and many other) bird species, which is in line with previous studies on the habitat preferences of *T. hindei* (Njoroge et al. 1998; Njoroge and Bennun 2000; Shaw et al. 2013, 2014).

Recent studies in the same study area showed that 97.4 % of all observation records of *T. hindei* are inside of dense thickets, mainly *L. camara*, which is assumed as being an important surrogate habitat for this bird species (Teucher et al. 2015). Individuals are well protected from predators like birds of prey and people who are hunting birds for consumption by these thickets (JCH, own observations). Thickets further serve as important feeding and breeding grounds (Teucher et al. 2015). Deforestation of previously interconnected and large riparian thickets leads to decreasing habitat size to increasing edge-size ratios, which might cause negative edge-effects (see Robinson et al. 1995; Castellon and Sieving 2006) and subsequent negative effects on the population viability. Negative effects from decreasing habitat quality (like and increasing level of habitat fragmentation) on the population structure of riparian forest birds was also reported for the Cerrado region of South America (Da Silva (1997), for riparian thickets in the Amazon forest (Lees and Peres 2008) and for the tropical uplands of Queensland (Crome et al. 1994). Martin et al. (2006) evidenced the high relevance of the habitat quality on species persistence. All these examples goes in line with our own results and underline the importance of dense and interconnected vegetation cover, being a prerequisite to build up high population densities and subsequent allow long-term population persistence in *T. hindei*.

Habitat configuration influences population structure

In addition to the availability of thicket patches, its spatial configuration might affect the population density of *T. hindei*. Our data support the fact that *T. hindei* occurs in distinct family groups, here consisting of an average of five individuals per family. This finding is congruent with previous observations of four to six individuals per family (ranging from 1–8 individuals) (Shaw et al. 2013). Our data reveal positive effects on the occurrence probability of *T. hindei* with increasing thicket coverage, as well as smaller distances among family groups in areas being characterised by dense vegetation cover. In turn, these findings underline the positive effect from intact riparian thickets, being the prerequisite for increasing densities, i.e. the co-existence of more family groups in smaller territories and shorter distances. In contrast, areas characterised by small and patchy thicket remnants are assumed to provide lesser resources and thus territories are larger and the geographic distances among families increase. This coherence is further supported by previous studies, indicating an increase in the size of territories with increasing fragmentation of remaining thicket patches (Shaw and Musina 2003).

Status quo and future trends

In summary, our data on the population ecology of *T. hindei* demonstrate that fragmented thickets may still provide suitable habitats, but ongoing fragmentation may lead to decreasing population density, and finally to a complete loss of this (and other) forest species. The land cover assessment along the three rivers revealed that 51.8 % of the total area is still covered by shrub vegetation. However, most of these thicket patches are small and isolated. The negative effects are reflected in the occurrence of *T. hindei* depending on thicket coverage along the three rivers. While high family densities can be observed in the still intact and interconnected vegetation along Kalundu and Nzeeu river, the situation at Ithiani river may indicate a worst-case scenario, with only one family group found in one of the few remaining thicket patches, surrounded by open land. However, *T. hindei* avoids crossing long distances of open land, and foraging can mainly observed in dense thickets (JCH, own observations). Thus, further habitat degradation and subsequent fragmentation of thickets might transform the previous spatial configuration from an interconnected line along rivers into few, small and geographically isolated thicket patches. In consequence, even if there still exists a large proportion of dense vegetation (‘potential habitat size’), the increasing level of fragmentation might lead to a strong reduction of the ‘effective habitat sizé, patches being still reachable and suitable for *T. hindei*. In consequence, the creation of corridors is of high importance to link potential habitats, and to transform the ‘potential habitat sizé into ‘effective habitat sizé for *T. hindei*. This would allow the preservation of its current population size and its long-term persistence, and might have positive synergistic effects for other species, and biodiversity in general (cf. Castellon and Sieving 2006).

Translating theory into conservation action

The fragmentation of formerly interconnected riparian thickets in our study region took place during the past decades, when demographic pressure and reduction of soil fertility have led to an increasing demand for fertile land for food crop production, and subsequently a transformation of pristine thickets into agricultural land (Habel et al. 2015; Teucher et al. 2015). Based on our data, conservation action should focus on locally adapted management practices allowing an optimal agricultural use of land along these rivers. Further, conservation actions have to be focused on the protection of intact habitat structures to conserve endangered biota (e.g. *T. hindei*). The design of an improved land-management (which preserves ecosystem services as well as habitats for endangered species could be as follows: Currently, most of the agricultural plots shortest side edge is oriented along the river and the longer edge mostly orthogonally faced from the river. With this rectangular structure in mind, the first 20 % of the plots (closest to the river) should be covered by pristine thicket. Adjoining to this section there should be another 20–25 % of fodder plants and other densely growing plants (resembling riparian thickets and providing potential surrogate habitats or effective corridors for many species). Behind that belt of dense vegetation (provision of habitats for biota as well as keeping ecosystem services intact, like protection against soil erosion, cf. Enanga et al. 2011), short distance to the river for watering purpose provide optimal conditions for planting low growing crops such as vegetables. With increasing distance from the riverbed, tall growing crops like maize, pigeon peas and other plants with a lower demand for water should be planted. Within this scheme, large single trees, e.g. *Calliandra calothyrsus*, *Gliricidia sepium*, and *Sesbania sesban* as fertilizer trees and *Terminalia browni* or *Senna siamea* for high value products (see Orwa et al. 2009) could provide further beneficial services, such as shade and fertilization for crops, but might also act as important stepping stones for various organisms (e.g. *T. hindei*, see Teucher et al. 2015). Pathways to access the agricultural plots should be consistently established either at the down- or upstream boundaries of the plots, giving access to two plots with just one source of interference to thicket formations. This may help to reduce disturbances on the remaining thickets. Such a management scheme might help to ameliorate human-wildlife-conflicts specifically in our study region, and along East African rivers—beyond prime areas of nature protection.

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