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Fitness of the pestiferous small rodent *Mastomys natalensis* in an agroecosystem in Mayuge district, Lake Victoria Crescent, Uganda

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Abstract: A 2.5-year study was conducted to understand the fitness of *Mastomys natalensis* in an agroecosystem in relationship with environmental predictors. The study was conducted in Mayuge district, in the Lake Victoria Crescent zone in Eastern Uganda. Fitness was measured in terms of survival, maturation and capture probability and estimated using multi-event capture-recapture models. Survival rates were higher after high rainfall in the previous month and increased with increasing population density of the animals. Maturation rate, on the other hand, showed no significant association with any predictor variables, while capture probability was significantly associated with sex of the animals, with higher capture probability for males. The results demonstrate that the fitness of *M. natalensis* in an agroecosystem is dependent on rainfall, sex and current population density. The aforementioned results were associated with increasing vegetation which provides cover for animal nesting and abundant food for the animals during rainfall periods and thus increased survival, high mobility in males in search for mates thus exposing animals to high chances of being captured and increased prey saturation at high population density resulting in high animal survival. These results have important implications for the timing of management strategies, i.e. control efforts should be enforced during the rainfall seasons to prevent high population buildup in the succeeding seasons.

Keywords: capture-recapture; *Mastomys natalensis*; maturation estimates; multistate model; survival.

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Introduction

The multimammate mouse (*Mastomys natalensis* Smith, 1834) is a serious rodent pest species in agriculture particularly in cereal crops in East Africa (Makundi et al. 1999, Stenseth et al. 2003). The multimammate mouse is a significant small rodent pest species in cereal crop production in Africa. Their occurrence is estimated to cause over 80% damage to maize in some locations and seasons and about 5–12% damage to field rice crop (Mulungu et al. 2003, 2015a,b, Mulungu 2017).

Currently, most pest managers use lethal control options whenever rodent population buildup is reported, but these have been shown to be less effective because animal resurgence after a short period after treatment (Leirs et al. 1997a,b) always results in unintended effects to non-target species in the environment (Singleton et al. 2007) and are expensive (Mdangi 2013; Mulungu 2017). Rodent populations tend to quickly recover following reduction events through reproduction or immigration from nearby populations (Leirs et al. 1997a,b, Cowan et al. 2003), which downplays the use of rodenticides to control rodents in a given locality. Consequently, as a strategy to improve current rodent control options, forecast models are arguably one important approach with the potential to predict rodent outbreaks (Leirs et al. 1996). Their application has been shown to be economically rewarding in controlling rodent population, as farmers would not spend money on control when it is not needed and only apply control when an outbreak is predicted thus mitigating losses (Davis et al. 2004).

Unfortunately, the currently available literature in the region offers limited and patchy information on how key ecological processes regulate rodent fitness and population size (Swanepoel et al. 2017). This thus limits the development of regional models for rodent prediction and early warning control systems for species inhabiting agricultural fields and surrounding areas. Development of appropriate rodent forecasting models requires an understanding of the key ecological aspects of the target species such as survival and maturation rates. These have been shown to be important in regulating rodent population changes (Oli and Dobson 2001, Lima et al. 2003, Sluydts et al. 2007). These traits are typically dependent on food and mate availability, vegetation cover and climatic conditions (Begg et al. 2005, Saïd et al. 2005, Hayes et al. 2007). Specifically, survival and maturation are important in regulating rodent populations over time and space; therefore, a solid understanding of these is critical to improve the prediction of future population changes for proactive rodent management (Leirs et al. 1997a,b, Witmer 2007).

In this study, we estimated maturation, survival and recapture probability of *Mastomys natalensis* as measures of animal species fitness in agricultural crop fields and surrounding fallow land. Knowledge on survival and maturation estimates can be employed to design more effective and appropriate predictive models to control rodent pest species at the most vulnerable stages (Witmer 2007).

Materials and methods

Study site

The study was conducted in Kigulu parish, Kigandalo subcounty, Mayuge district in Eastern Uganda (06°16′S, 37°31′E), approximately 1020 m above sea level (Figure 1). The study area experiences a bimodal rainfall pattern, characteristic of Eastern Uganda in the Lake Victoria Crescent agro-ecological zone. The first rainy season normally occurs between March and end of May followed by a short dry period (June–August). The second rainy season starts toward the end of August to end of November, and then a dry spell from December to February of the following year. The zone is characterized as a banana-coffee system, majorly engaged in growing crops including bananas, coffee, maize, sweet potato, beans, vegetables and rice (Musiitwa and Komutunga 2001, Haneishi et al. 2013). Farming in this zone is majorly done by small-scale farmers with mean farm plots of about 1.5 acres (0.6 ha) (Haneishi et al. 2013). Due to the intense demand for agricultural and pasture land, there is a lot of land use intensification and fragmentation and thus natural habitats and forests occur in small patches.

Trapping fields/grids

Permanent trapping fields for the experiment were obtained with the agreement of the landowners. A purposive sampling technique was used in the selection of study fields, and targeted both crop cultivated field habitats and fallow land habitats. Each of the two categories was replicated twice making a total of four trapping fields, separate from each other at a minimum distance of 500 m to avoid population immigration from one grid to another (Borremans et al. 2015). At each of the identified field sites, a 60 m×60 m grid was marked with 49 permanent trapping points, for the placement of 49 Sherman live traps during each trapping session. The fallow land fields were initially covered with heavy thick patches of tick berry (*Lantana camara*) but were subsequently reduced by animal grazing. Other weedy species noted were perennial and annual grasses (Gramineae) of several species, which are common in disturbed soils and uncultivated fallow lands. They included guinea grass (*Panicum maximum*), couch grass (*Digitaria scalarum*), black jack (*Bidens pilosa*), star grass (*Cynodon dactylon*) and wandering Jew (*Commelina benghalensis*). The fallow fields were surrounded by cultivated fields which, during the wet season, were planted with maize, beans, cassava and sweet potatoes. After crop harvest, these fields were left with standing stubble and slash and ox-plough were the main land preparation methods before the next wet/planting season started.

The cultivated fields were found already planted with maize intercropped with beans by the farmers in the first year of the study (2016) but in the subsequent seasons, the farmers introduced cassava as a way of crop rotation to control witchweed (*Striga* sp.) (Oswald and Ransom 2001) in the area. Fragments of mixed crop gardens comprising coffee, beans, bananas, sweet potato and cassava also surrounded these cultivated study fields.

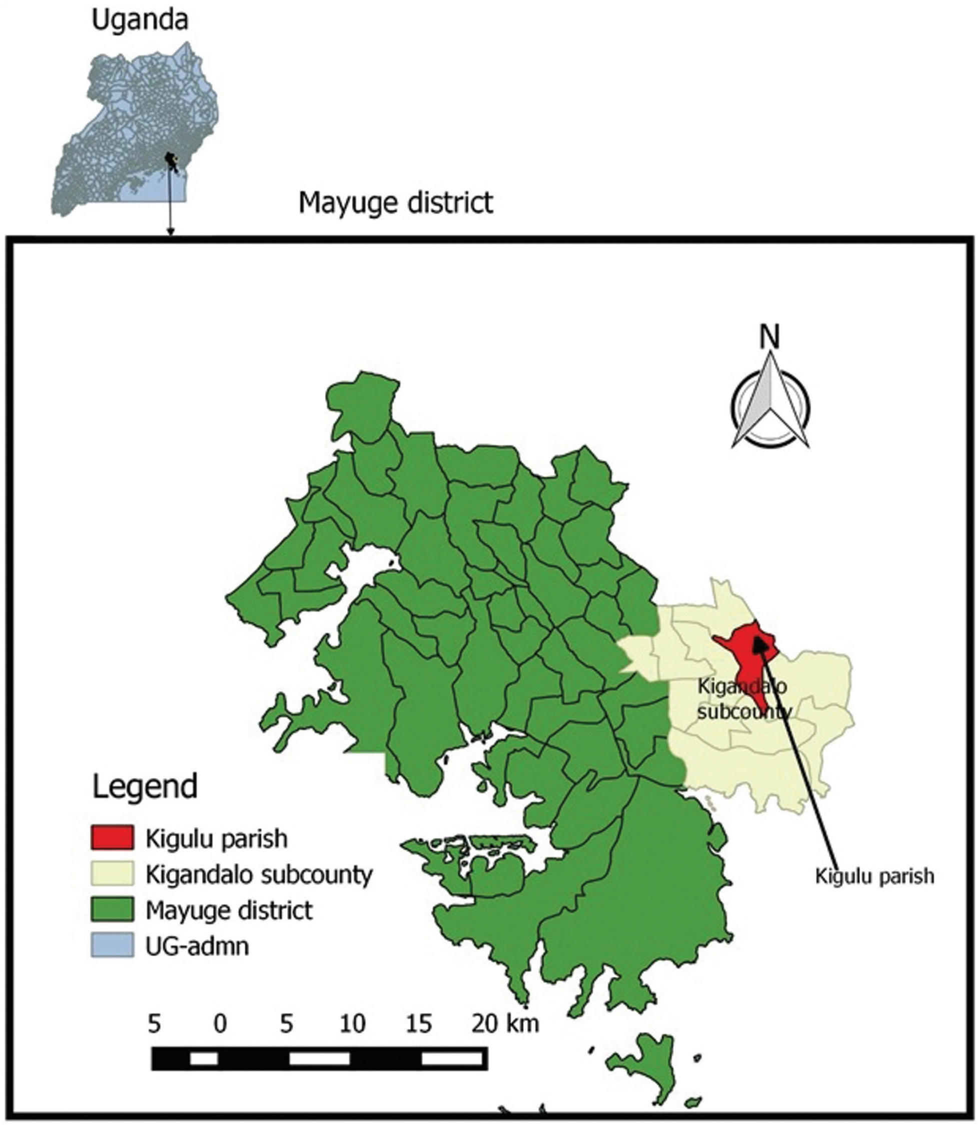

Figure 1: Location of the study site, Kigandalo subcounty, Mayuge district, Eastern Uganda.

Trapping procedure

The trapping procedure followed that of Aplin et al. (2003) using the capture mark release trapping technique. Sherman live traps (Light Folding Aluminum, 7.6×8.9×22.9 cm, H.B. Sherman Traps, Inc., Tallahassee, FL, USA) were used to trap the rodents. Traps were baited with peanut butter mixed with maize flour and the trapping sessions were conducted at 4-weekly intervals for 3 consecutive days. At every trapping session, traps were inspected every morning and the captured animals were checked for sexual maturity status, weighed, toe clip coded and released at the points of capture. The study lasted for 2.5 years from January 2016 to May 2018. The nomenclature by Wilson and Reeder (2005) and Happold (2013) was used as the main reference to identify the rodent species captured in the study areas.

Statistical analysis

Survival, maturation and capture probability were estimated using multi-event capture-recapture models (Pradel 2005) in E-SURGE V2.1.4 (Choquet et al. 2009a). Survival was defined as the monthly probability for an individual to survive from one month to the next, while maturation was defined as the monthly probability for a juvenile to become an adult.

Survival and maturation were hypothesized to be affected by various biological and environmental factors including sex, field habitat (fallow and cultivated fields), previous rainfall and current rodent population density. These were categorized in order to study their effects on survival and maturation. For each month, we calculated the sum of the total rainfall in the two previous months. The mean value for each month was 406 mm rainfall (range = 98–1145 mm). Rainfall was thus categorized into three: low rainfall (less than 300 mm), medium rainfall (between 300 and 500 mm) and high (more than 500 mm).

Due to the low number of recaptures, it was not possible to calculate the density in each field for each trapping session. Therefore, the mean unique individuals trapped in all fields for each month was calculated and divided into two categories: low (average lower than 10 individuals) and high (average higher than 10 individuals) density.

A goodness-of-fit (GOF) test was carried out using the program U-CARE prior to the survival analysis to evaluate potential confounding factors such as an excess of transient animals and trap dependence (Pradel et al. 2003, Choquet et al. 2009b). The GOF test showed that there were no deviations indicating trap dependence (see Results), which suggests that animals trapped in the previous trap night have the same probability of being recaptured as individuals that were not trapped in the previous trap night. Additionally, the GOF test showed no excess of transient individuals (see Results), meaning that there was no difference in the probability of being captured for the first time compared to subsequent recaptures (Rémi et al. 2005, Choquet et al. 2009b).

Survival analysis

A multivariate multistate Cormack-Jolly-Seber model with three potential states, subadult, adult and dead, was used. This allowed us to estimate the probability of three events: apparent survival (φ), maturation (ψ) and recapture (P). As mentioned before, trapping was done using Pollock's closed robust design, where the population is assumed to be closed (i.e. no entry or exit of individuals into the population) within each trap session and open between trapping sessions (Pollock 1982). Monthly survival was estimated between each trapping session and fixed to 1 within a trapping session, while the capture probability was estimated within each session.

The three parameters were modeled in subsequent steps: first we modeled maturation, then recapture probability and lastly survival (Sluydts et al. 2007, Mariën et al. 2018). Models were ranked using Akaike's information criterion (AICc) (Burnham and Anderson 2004), where the model with the lowest AIC value was selected as a starting point for the next modeling step. Recapture probability was fully time dependent in all models during the first two modeling steps (maturation) and we allowed survival to differ with cumulative rainfall of the past 2 months, as this has been shown to affect survival in *Mastomys natalensis* (Julliard et al. 1999, Sluydts et al. 2007). All three parameters were allowed to vary between sex (male and female) and field (fallow or cultivated). Survival and maturation probability were allowed to differ between density (high or low) and with cumulative rainfall of the last 2 months (high, medium or low) in the full model with a potential interaction between them. Lastly, Sluydts et al. (2007) found that survival in *M. natalensis* differed between subadults and adults and hence reproductive age was included in the final model as well.

Ethical considerations

This research was carried after a thorough review by Wildlife department, Sokoine University of Agriculture, Tanzania. Further research approval was obtained from the Uganda Wildlife Authority for conducting research on live animals in Uganda (UWA/COD/96/05).

Results

In the capture mark release data set, there were 1030 captures of *Mastomys natalensis* with 550 unique individuals.

Goodness of fit

The GOF showed no deviations against the assumption of transience (test 3G.SR, $\chi^2 = 57.653$, df = 77, p = 0.951) nor against trap dependence (test M.ITEC, $\chi^2 = 50.612$, df = 39, p = 0.101). This allowed further analysis of the data without any biased estimates due to transience or trap dependence.

Model selection

We first modeled maturation and found that the model with the lowest AICc value was the model where the maturation probability per month was constant through time [ψ_{cte}: AICc = 3399.9, deviance = 3333.6, number of parameters (Np) = 32; Table 1]. We therefore kept maturation probability constant in the subsequent modeling steps. During the second modeling step, the recapture model with the

Table 1: Modeling of maturation, recapture and survival.

Model no.	Maturation (ψ)	Recapture (P)	Survival (ϕ)	Np	Deviance	AICc	ΔAICc
1	**cte**	**T**	**R**	**32.0000**	**3333.5852**	**3399.8985**	**0.0000**
2	D	T	R	33.0000	3332.3422	3400.8027	0.9042
3	R	T	R	34.0000	3330.6304	3401.2429	1.3444
4	R*D + S	T	R	39	3320.0948	3401.5385	1.6400
5	S	T	R	33.0000	3333.1017	3401.5622	1.6637
6	R*D + F	T	R	39	3320.4671	3401.9108	2.0123
7	F	T	R	33.0000	3333.5173	3401.9778	2.0793
8	R*D	T	R	37.0000	3326.2896	3403.3865	3.4880
9	D + S	T	R	35.0000	3330.6337	3403.4029	3.5044
10	R*D + S + F	T	R	40.0000	3319.9980	3403.6223	3.7238
11	S + F	T	R	34.0000	3333.0451	3403.6576	3.7591
12	R + S	T	R	36.0000	3328.9926	3403.9233	4.0248
13	D + F	T	R	35.0000	3331.3692	3404.1385	4.2400
14	R + F	T	R	36.0000	3329.8127	3404.7434	4.8449
15	R + F	T	R	36.0000	3330.3801	3405.3108	5.4123
16	D + S + F	T	R	36.0000	3330.6319	3405.5626	5.6641
17	R + D + S	T	R	37.0000	3328.6842	3405.7812	5.8827
18	R + D + F	T	R	37.0000	3329.6458	3406.7427	6.8442
19	R + D + S + F	T	R	38.0000	3328.6551	3407.9230	8.0245
20	**cte**	**T + S**	**R**	**33**	**3329.2526**	**3397.7131**	**0.0000**
21	cte	T + S + F	R	34	3327.8097	3398.4222	0.7091
22	cte	T	R	32	3333.5852	3399.8985	2.1854
23	cte	T + F	R	33	3332.2922	3400.7528	3.0397
24	**cte**	**T + S**	**R*D + F**	**37**	**3315.2497**	**3392.3466**	**0.0000**
25	**cte**	**T + S**	**R*D**	**36**	**3318.2209**	**3393.1516**	**0.8050**
26	cte	T + S	R*D + S + F	38	3314.3285	3393.5964	1.2498
27	cte	T + S	R*D + A + F	38	3314.8579	3394.1258	1.7792
28	cte	T + S	R*D + S	37	3317.3395	3394.4364	2.0898
29	cte	T + S	R*D + A	37	3317.7803	3394.8772	2.5306
30	cte	T + S	R*D + A + S + F	39	3313.994	3395.4377	3.0911
31	cte	T + S	R*D + A + S	38	3316.9563	3396.2242	3.8776
32	cte	T + S	R + F	34	3325.7841	3396.3966	4.0500
33	cte	T + S	R	33	3329.2526	3397.7131	5.3665
34	cte	T + S	R + A + F	35	3325.224	3397.9933	5.6467
35	cte	T + S	R + S	34	3328.1635	3398.776	6.4294
36	cte	T + S	R + A + S + F	36	3324.1977	3399.1284	6.7818
37	cte	T + S	R + A	34	3328.6013	3399.2138	6.8672
38	cte	T + S	R + A + S	35	3327.5857	3400.355	8.0084
39	cte	T + S	F	32	3335.2957	3401.6089	9.2623
40	cte	T + S	cte	31	3338.3889	3402.5596	10.2130
41	cte	T + S	A + F	33	3334.6598	3403.1203	10.7737
42	cte	T + S	S + F	33	3334.6598	3403.1203	10.7737
43	cte	T + S	D + F	33	3334.8849	3403.3454	10.9988
44	cte	T + S	S	32	3337.3756	3403.6889	11.3423
45	cte	T + S	A	32	3337.6743	3403.9875	11.6409
46	cte	T + S	D	32	3337.9831	3404.2963	11.9497
47	cte	T + S	A + S + F	34	3333.7407	3404.3532	12.0066
48	cte	T + S	D + S + F	34	3333.8551	3404.4676	12.1210
49	cte	T + S	D + A + F	34	3334.3015	3404.914	12.5674
50	cte	T + S	A + S	33	3336.7421	3405.2026	12.8560
51	cte	T + S	D + S	33	3336.933	3405.3936	13.0470
52	cte	T + S	D + A	33	3337.3237	3405.7842	13.4376
53	cte	T + S	D + A + S + F	35	3333.3468	3406.116	13.7694
54	cte	T + S	D + A + S	34	3336.3562	3406.9687	14.6221

Highlighted (bold) models were the best models (with the lowest AICc) and were selected in each step and used as a starting point for the subsequent step. For each model, the number of parameters (Np), deviance and AICc are given. ΔAICc is the difference in AICc between the current model and the top ranked one. Abbreviations: A, reproductive age (subadult or adult); D, current density (categorical: high or low); F, field type (fallow or cultivated); R, cumulative rainfall of the previous 2 months (categorical: low, medium or high); S, sex (male or female); T, full time dependence where the probability could change every trapping session; cte, model with no fixed effects, only an intercept.

lowest AICc value had an additive effect between time and sex (P_{T+S}: AICc = 3397.7, deviance = 3329.3, Np = 33; Table 1). Another recapture model with field as an extra additive effect (P_{T+S+F}: AICc = 3398.4, deviance = 3327.8, Np = 34; Table 1) was only one AICc unit removed from the best fitted recapture model. Lastly, we modeled survival where the model with the lowest AICc value had an interaction between rainfall and density and an additive effect of field (φ_{R*D+F}: AICc = 3392.3, deviance = 3315.2, Np = 37; Table 1).

However, the survival model with only the interaction between rainfall and density (φ_{R*D}: AICc = 3393.2, deviance = 3318.2, Np = 36) was less than one AICc unit removed from the best fitted survival model, suggesting that they both adequately fit the data. Indeed, the interaction between rainfall and density seemed important, as all models with the lowest AICc value included this interaction. We therefore chose the final best fitting model with the lowest AICc and lowest number of parameters which contained the following factors: ψ_{cte}, P_{T+S}, $\varphi_{R*D.}$

Maturation estimates

From the best fitting model (as described earlier), we found a monthly maturation probability of 0.13 [95% confidence interval (CI): 0.09, 0.18]. This value did not differ between males and females, nor did it change with density or rainfall.

Recapture estimates

To account for differences in trapping effort over the months, we allowed the recapture estimates to change monthly. We found that there were differences in recapture estimates through time with a minimal recapture probability of 0.01 (95% CI: 0.00, 0.04) and maximum of 0.43 (0.19, 0.70; Figure 2). The best fitting model included, besides this time dependence, an additive effect of sex where males had, on average, a higher recapture probability of 0.04 (min = 0.002, max = 0.07) than females (Figure 2).

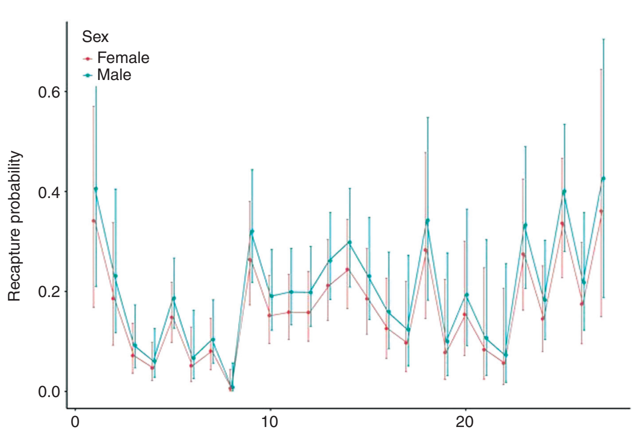

Figure 2: Recapture probability of males (blue lines) and females (red lines) for every trapping session.
Error bars represent the 95% confidence intervals of each estimate.

Survival estimates

Our final model revealed that survival in *Mastomys natalensis* was affected by an interaction between cumulative rainfall in the past 2 months and current density. There were no real differences in survival probability between low [0.50 (0.40, 0.61)] and high density [0.43 (0.35, 0.52)] when rainfall in the past 2 months was low (Figure 3). However, when rainfall increased in the previous 2 months, there were clear differences in survival probability between high and low densities. When the cumulative rainfall in the previous 2 months was between 300 and 500 mm, survival probability in high densities was higher [0.85 (0.50, 0.97)] than when density was low [0.61 (0.49, 0.71)]. This discrepancy in survival probability between

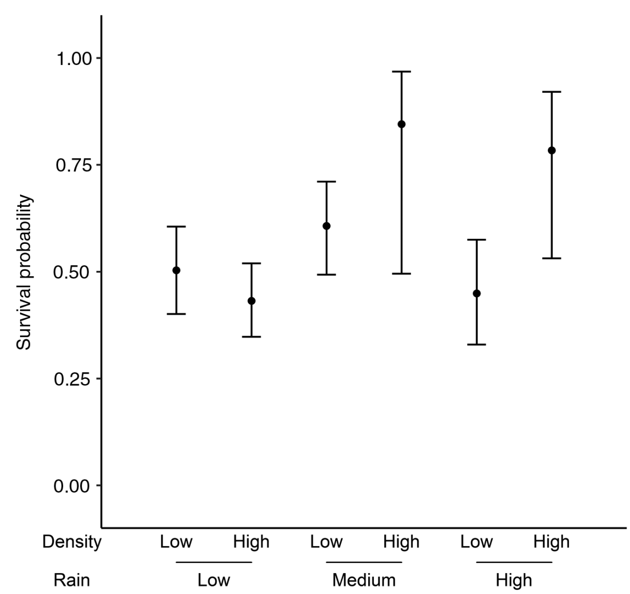

Figure 3: Monthly survival probability of *Mastomys natalensis* in periods where cumulative rainfall in the last 2 months was lower than 300 mm (low), between 300 and 500 mm (medium) or higher than 500 mm (high).
Within these periods, there were differences in survival probability when current density was low (<10 captured individuals) or high (>10 captured individuals). Error bars represent the 95% confidence interval.

high [0.78 (0.53, 0.92)] and low [0.45 (0.33, 0.57)] densities became even larger when rainfall in the last 2 months was higher than 500 mm (Figure 3).

Discussion

In this study, survival and maturation were the key demographic processes investigated as they have been shown to play a significant role in rodent population dynamics and can be utilized to improve the timing of application of poisons for effective control of rodents (Lima et al. 2003). Additionally, the recent scientific developments emphasize an ecologically based rodent control approach with the integration of forecasting systems (Davis et al. 2004, Palis et al. 2011); therefore, understanding survival and maturation processes will improve the forecasting systems. Regionally, while considerable information on survival and maturation of *Mastomys natalensis* and how these traits shape population abundance exists, these are majorly concentrated in Tanzania and thus regional models are not feasible (Swanepoel et al. 2017). For example, survival and maturation have been studied and results are variable and dependent on both density-dependent and density-independent factors (Leirs et al. 1994, Sluydts et al. 2007, Massawe et al. 2012, Mulungu et al. 2015a,b). These demographic characteristics play a significant role in regulating population growth and have been identified as important aspects in regard to rodent pest management in any given geographical location (Leirs et al. 1994, Lima et al. 2003, Sluydts et al. 2007).

In this study, maturation rates were not influenced by the different variables (rainfall, population density, age, sex and habitat). The results thus differ from earlier studies that have shown clear relationships with some of the mentioned response variables (Leirs et al. 1997a,b, Sluydts et al. 2007). For example, Leirs et al. (1997a,b) estimated the maturation rate of female *Mastomys natalensis* to increase with an increasing amount of preceding rainfall, which is a trigger for increased food availability for the animal's quick maturation. The insignificant relationship in our study may thus possibly be attributed to the mosaic mixed cropping system in the study area, a scenario which could possibly have offered a diversity of foods to the surviving animals for normal growth and development even during periods of absence of seasonal crops like maize, beans and other cereals. It is likely that the animals consumed other available tuber food crops including sweet potatoes and cassava, which comprise almost the same nutrients like the cereals for normal growth and development (Amagloh et al. 2015).

Alternatively, the low recapture numbers obtained in the study might have possibly affected the attainment of significant effects of the various studied response variables on maturation rates of the animals. In another closely related study on maturation estimates of field voles in Europe, it was observed that maturation estimate studies may need to be conducted in large outdoor enclosures and monitored more closely, about 7–10 days' interval to easily capture the sudden changes in growth (Eccard et al. 2002). Therefore, an additional outdoor enclosed experiment or a trapping at more regular intervals (7–10 days) could provide more reliable data to estimate the effect of sex, rainfall and population density of the animals on maturation rates of *Mastomys natalensis* in Uganda.

Survival

On the other hand, survival in *Mastomys natalensis* was affected by an interaction between cumulative rainfall in the past 2 months and current population density. Model estimates revealed higher survival rates during medium to high rainfall (300 mm and above) and were more pronounced when population density was high (above 10 animals/ha). These findings are in agreement with earlier studies that reported higher survival rates of small rodents in rainfall seasons (Lima et al. 2001; Sluydts et al. 2007). Abundant rainfall is reported to result in increased availability of food resources for rodents and abundant vegetation cover, which provides protection to rodents from predatory animals thus increasing their chances of survival (Leirs 1992; Mlyashimbi et al. 2018). Consequently, during the dry seasons (low rainfall) there is reduced vegetation cover which is likely to expose the animals to predation. The aforementioned condition results in reduced food resource availability and thus increased competition for food among animals which is reported to affect survival rates (Lima et al. 2001).

Secondly, our study reports discrepant results of higher survival at higher population densities. Most previous studies have demonstrated low survival at higher animal densities (Leirs et al. 1997a,b, Sluydts et al. 2007). The contrary results in our study could have originated from two possible phenomena: the generally low population density during the study which could only allow two population density categories, low density (less than 10 animals/ha) and high density (above 10 animal/ha). When compared with similar referenced studies earlier, they report up to about 300 animals/ha at high population density. Therefore, our categorization of more than 10 individuals/ha as high may be still a small number to result in significant competition for the available resources to cause a negative effect on animal survival. In fact, Leirs et al. (1997a,b) suggested that studies on the effect of density-dependent factors are more effective when conducted on highly fluctuating populations. Alternatively, the findings could be attributed to the effect of reduced predation as a result of the prey saturation effect when animals were more than 10 compared to when there were less than 10 individual animals/ha, thus increasing the survival probability at high density. The latter explanation was also suggested by Julliard et al. (1999) as one possible reason for the positive survival effect on subadult *Mastomys natalensis* at high population density. The findings further confirm that density indeed affects demographic characteristics differently under different selection pressure as predicted by earlier theories of life history evolution (Schaffer 1974, Charlesworth 1994).

On the other hand, this study showed that sex and age of the animals had no significant relationship with survival of *Mastomys Natalensis*, whereas earlier studies in the East African region showed that they significantly influence survival (Leirs 1995, Julliad et al. 1999, Sluydts et al. 2007). This phenomenon may be backed up by Lidicker's (1978) earlier study which predicted that demographic variations can occur within same species among different populations. Therefore, the population of *M. natalensis* in Uganda seems to differ from the other populations in the region as age and sex do not affect survival compared to other populations in Eastern Africa.

Recapture

In terms of recapture probability estimates, this study demonstrated higher recapture probabilities for males compared to females. Explanation to this finding could be that males tend to exhibit high mobility when they are sexually mature as they roam around in search for multiple mates (Kirkland and Layne 1989, Kennis et al. 2008). The increased male mobility has been shown to result in increased exposure to predation (Koivunen et al. 1996), pathogens (Isaac 2005) and also reduced foraging time as animals are exposed to unfamiliar habitats (Skorping and Jensen 2004). Secondly, another possible explanation for high recapture probability for males in this study could be linked to the different home range sizes for the different sexes in *Mastomys natalensis*. For example, adult females have been shown to have smaller home ranges during breeding seasons as they stay close to their burrow to feed pups or to protect them against infanticide (Ebensperger and Blumstein 2007, Borremans et al. 2014, Stacey et al. 2017).

Conclusion

This study has shown that the fitness of *Mastomys natalensis* as demonstrated through survival, maturation and recapture probability was variable in the agroecosystem in the Lake Victoria Crescent in Uganda. Specifically, animal survival was enhanced when rainfall appeared in the last 2 months and when current animal population density was high. Rainfall as a factor is associated with increasing vegetation, which provides both quality and quantitative food but also offers nesting sites for the animals. These results have thus shown that the fitness of *M. natalensis* is highly dependent on vegetation which is produced as a result of rainfall. Management efforts should therefore be timed and concentrated during the rainy seasons, when vegetation is abundant to prevent further population buildup in the following months which could result in high crop damage. In addition, fitness measured in terms of recapture probability showed that females have less chances of being recaptured. The results have important applications on the management strategy to be applied, for example, the use of traps may not be efficient in controlling female populations and thus their capture rates are low.

On the contrary, the maturation rate of the animals was not significantly influenced by sex, rainfall and population density in this study. The unique results were attributed to possibly be due to the low recapture rates of the animals in the study which could have affected the attainment of variations in maturation rates to obtain significant relationships with predictor variables. To a lesser extent, the authors link the mixed cropping system practiced in this area to have offered a diversity of foods to the animals and thus the animals were not constrained by the effect of lack of nutritious food for normal growth. Nonetheless, the authors propose a large outdoor enclosed experiment to generate more conclusive information, as it will allow a closer monitoring of the same animals in the population for a specified period of time as proposed by Eccard et al. (2002).

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