

**Survival and recruitment of the multimammate mouse, *Mastomys natalensis* (Smith 1834),
in a rice agro-ecosystem**

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Abstract

We investigated the recruitment and survival of the multimammate mouse, *Mastomys natalensis*, within irrigated rice and fallow field habitats at different time periods related to rice crop growth stages. Capture-Mark-Recapture data were collected for *M. natalensis* each month from June 2010 to May 2012, and both recruitment and survival were estimated in relation to land use (irrigated rice or fallow field) within the agro-ecosystem. Higher recruitment and survival were

observed in rice fields than in fallow fields suggesting the relationship was compensatory when there was a higher abundance of food resources. In terms of management, farmers in the study area should implement management strategies in rice fields at both transplanting and maturity stages of crop growth in order to maintain recruitment and survival at low levels.

Keywords: rodent, agriculture, population dynamics, rice cropping, pest management

Introduction

Rodents living in human influenced landscapes have to cope with or adapt to the direct or indirect consequences of human activity. In addition, pest rodents are described as opportunistic species, characteristically conforming to an r-selected strategy when reproductive conditions are favourable (Leirs et al., 1997). Massawe et al. (2012) reported that interactions between humans and rodents can have detrimental effects on survival and recruitment. For example, in Tanzania farmers produce rice crops twice per year in irrigated agro-ecosystems, one during the rainy season and another during the dry season exclusively under irrigation. Mulungu et al. (2013) reported that the population size of *M. natalensis*, which is the major rodent pest in this environment, varied with habitat and by season. Populations were higher in fallow land compared with rice fields, and the highest population peak was observed during the dry season (July to October). Furthermore, individual rodents bred throughout the year but with a peak coinciding with crop maturity.

Despite some knowledge of the population dynamics and breeding patterns of *M. natalensis* in rice agro-ecosystems (Mulungu et al. 2013), their survival and recruitment within this system is not well-known. Recruitment and survival can differ between agro-ecosystems as

described by Massawe et al. (2005) which reported that recruitment and survival rates of *M. natalensis* were higher in slash-and-burn compared to tractor-ploughed maize fields. Similarly, Kennis et al. (2012) reported that survival of *Deomys ferrugineus* in primary forest was higher than in fallow land over a period of four weeks with increased survival potentially linked to higher abundance of the species main food resources, insects and termites.

The annual population cycle of *M. natalensis* in maize dominated crop fields is comprised of a population decline during the rainy season followed by a dry season increase (Leirs et al. 1994), where population growth patterns are associated with rainfall (Leirs et al. 1994). Young animals' growth is inhibited at the end of the dry season (October-November) and growth is only resumed after the first heavy rains. This typical annual cycle of *M. natalensis* could reflect a decline due to a low survival rate of the first litters or a dilution of the population through dispersion into temporary habitats during the wet season followed by the return of individuals to fields in the early dry season (Leirs et al. 1994) or due to better habitat support for food which will influence survival and earlier maturation (Leirs 1992). Thus, survival of *M. natalensis* is reported to be higher during the wet season, corresponding to the cropping season, whereas survival is low during the dry season arguably due to insufficient intake of food and increased competition (Massawe et al. 2012). High quality and abundant food during the wet season has been reported to result in faster growth and better survival for *M. natalensis* in maize cropping (Leirs et al. 1990). Similar studies on the recruitment and survival of *M. natalensis* in irrigated rice systems are lacking, and such knowledge is critical for the control of pest species as these factors determine whether the rate of control is sufficient to keep the population of the pest at low levels. Therefore, the aim of this study was to investigate the recruitment and survival of *M. natalensis* in an irrigated rice agro-ecosystem.

2. Material and Methods

2.1 Study area

This study was conducted at Hembeti village (06°16'S, 37° 31'E), in Mvomero District, Morogoro, Tanzania. The study area has a bimodal rainfall pattern with short rains falling from October to December and long rains from March to June. Agricultural cropping patterns in Tanzania typically consist of a relatively small-scale matrix of agricultural fields and fallow land (Odhambo et al. 2005). In this study area, some patches of fallow land exist within the irrigated rice ecosystem. Within fallow areas the following plant species can be found in variable abundance: Black jack, *Bidens pilosa* (Compositae); Elephant grass, *Pennisetum purpureum* (Gramineae); Guatemala grass, *Tripsacum duxum* (Gramineae); Nut grass, water grass, *Cyperus rotundus* (Cyperaceae); *Cyperus esculentus* (Cyperaceae); Star grass, couch grass, *Cynodon dactylon* (Gramineae); *Digitaria scalarum* (Gramineae); *Imperata cylindrica* (Gramineae); and Water velvet, *Azola africana* (Salviniaceae). The average farm size in the study area is 0.5 to 1.5 acres, and farmers produce two rice crops per year. The first crop is planted during the wet season from January to June and the second one is during the dry season from July to December, exclusively dependent on irrigation. Land preparation and rice transplanting are conducted in January and July during the wet and dry seasons, respectively. The rice crops reach physiological maturity in May and November and farmers harvest in June and December for wet and dry seasons, respectively. The booting stage is in April and October for wet and dry seasons, respectively. The rest of the cropping period, February - March for wet season and August - September for dry season, is the vegetative crop growth stage.

2.2 Trapping rodents

A Capture-Mark-Recapture (CMR) study was carried out from June 2010 to May 2012. Four 70 x 70 m trapping grids, two in rice and two in fallow mosaic fields, were permanently established. The size of the grids correspond with the approximate size of the farmers field where the boundaries from one field to another were the bunds around the fields. A distance of >300 m was set between each CMR grid. Each grid consisted of seven parallel lines, 10 m apart, and seven trapping stations per line, also 10 m apart (total of 49 trapping stations/grid). One Sherman LFA live trap (8 x 9 x 23 cm, H.B. Sherman Traps Inc., Tallahassee, FL, U.S.A.) was placed at each trapping station and all were set for three consecutive nights at intervals of four weeks for a total of 24 trapping sessions. Traps, baited with peanut butter mixed with maize bran/maize flour, were placed in the afternoon and inspected in the morning. During flooding, the traps were placed on top of dry grass clumps in grid locations.

2.3 Captured animals

Data presented in this study is focussed on *Mastomys natalensis* (Smith 1834), which represented more than 95% of all captures. However, four other rodent species were also captured at the site, viz: *Dasymys* cf. *incomtus*, *Rattus rattus*, *Grammomys dolichurus* and *Acomys* cf. *spinosissimus*. Captured animals were treated in a humane manner and in compliance with the 1964 Helsinki Declaration (7th revision) and guidelines of the American Society of Mammalogists (Sikes and Gannon 2011). The research study also follows the ethical regulations of Sokoine University of Agriculture, and all procedures of acquiring permits from the local authority to carry out the studies in the designated area were strictly adhered to. All captured animals were taken to the field laboratory and identified to species level (Kingdon 1997). On the first day of capture, all

animals were marked by toe clipping using an established coding system (Borremans et al. 2014). For each capture the trap station was recorded along with the animal's sex, weight and reproductive condition (males were either scored as scrotal or non-scrotal and females as perforate or imperforate vagina, lactating or pregnant through palpation). The animals were then released at the same location of capture.

2.4 Data collection and Analysis

2.4.1 Recruitment

We defined recruitment as the temporal measure of the proportion of new individuals brought into the population (Massawe et al., 2005). We estimated the rate of recruitment as the proportion of new individuals entering the trappable population during the entire study period. The number of unmarked animals out of the total capture for each trapping session was used to establish the proportion of new recruitment into the population. The proportions of new individuals were compared between months, crop growth stages and habitats employing a repeated measure analysis within a generalised linear model using the statistics programme Statistica (Dell Software).

2.4.2 Survival

As *Mastomys natalensis* was captured in high numbers during the study period, we were able to estimate species survival using the Cormack-Jolly-Seber (CJS) model (Lebreton et al. 1992) using the software programme MARK (White & Burnham 1999; White 2008). The capture history (CH) database consists of columns indicating each primary trapping session and rows for each individual capture history where a *zero* entry indicates that an individual was not

encountered in that particular month and a *one* indicates it was encountered at least once in that trapping session (Pollock et al.1990). A variety of models that included the factors of time, habitat (rice or fallow field) season (wet or dry season) and cropping stage (transplanting, vegetative, booting, and harvesting) were tested for goodness-of-fit using the full CJS model with time-dependent survival (ct) and recapture probabilities (pt). To test the main effects of different factors and their interactions, we used the software programme MARK (White & Burnham 1999, White 2008). To select the most appropriate model, we used the Akaike Information Criterion (AIC) corrected for the effective sample size (Lebreton et al. 1992): $AIC = DEV + 2k + 2k[n/(n - k - 1)]$, where DEV represents the deviance $[-2\ln(L)]$, L the likelihood of the model evaluated at maximum likelihood estimates, k the number of separately estimated parameters in the model, and n the effective sample size. The models were ranked using the difference between the AIC of the model and the AIC of the best model (referred to as ΔAIC). ΔAIC can be interpreted according to this scale: models having $\Delta AIC \leq 2$ are strongly plausible alternatives to the best model, those where $4 \leq \Delta AIC \leq 7$ are considerably less plausible whereas models having a $\Delta AIC \geq 10$ are improbable (Burnham and Anderson 2002). In this case, for the sake of parsimony, we considered the best model was the one with the fewest parameters. All mean values are quoted with \pm SE.

3 Results

3.1 Recruitment of new individuals

We hypothesized that variation in the recruitment of *M. natalensis* is closely associated with varying conditions created in the environment through different habitats in irrigated rice agroecosystems. Over the study period, the month ($F_{11, 67} = 543.60$, $p = 0.13$) had no significant effect

on the proportion of new individuals entering the trappable population, and there were no interactions between month and habitat ($F_{11, 67} = 191.69$, $p = 0.55$). However, the proportion of new individuals entering the trappable population differed significantly between habitats ($F_{1, 67} = 11.47$, $p = 0.00$) showing more individuals entering the trappable population in the rice fields (60.92) compared to fallow land (47.24) (Fig. 1). Furthermore, it was observed that the proportion of new individuals entering the trappable population was higher during transplanting (mean = 0.62 ± 0.05) and harvesting time (mean = 0.63 ± 0.05) compared with the booting stage (mean 0.45 ± 0.05) in both habitats (Fig. 1). However, no significant difference was observed between the two seasons ($F_{1, 60} = 0.60$, $p = 0.42$), with the percentage recruitment of the dry season = 55.35 and the wet season = 52.70, $LSD_{0.05} = 6.50$.

3.2 Survival

The best model represented survival varying with habitat and cropping stage, and recaptures varying with time (Table 1). However, the next best model, which differed by an AICc of 3.06, represented survival varying with habitat and time, and recaptures varying with time (Table 1). There were no other competing models, and the next best model, which comprised survival varying with habitat, and recaptures varying with time, was not well supported (AICc weight = 0.003) (Table 1). Based on the best model of survival varying with habitat and cropping stage, the monthly survival of *M. natalensis* varied significantly over the study period, depending on the cropping stage and the type of habitat (Fig. 2). The survival rate followed a similar trend from transplanting to harvesting in the two different habitats, and in general, was observed to be higher in the rice fields at all cropping stages compared with the fallow land (Fig. 2). In the fallow land, the survival rate varied from 0.29 – 0.58 where the lowest survival rate was

observed during the booting and vegetative stages and the highest was during the harvesting period. In contrast, in the rice fields the survival rate ranged from 0.48 – 0.67, which was similarly highest during the harvesting period (Fig. 2).

4 Discussion

Many pest rodents can survive and reproduce successfully under a fluctuating environment (Mulungu et al. 2013, Massawe et al. 2011), and when conditions change, they can modify their behaviour to suit the new conditions. Therefore, rates of survival and recruitment are necessary components of models that describe and explore the causes of changes in the size of animal populations (Massawe et al. 2012). In the present study it was observed that recruitment of new individuals into the population was higher in the rice fields compared with fallow land. This could be explained by rodents from surrounding areas being more attracted to the rice field, which was most apparent at transplanting and harvesting time where recruitment was highest. Mulungu et al. (2014) reported that vegetative plant material and seeds were the main types of food consumed by *M. natalensis*, not only due to their relatively higher abundance in the environments under study but also because of the species' highly specialised herbivorous/granivorous nature. Recruitment was observed to be low at the booting stage and this could be due more to reasons of seeking shelter, a behaviour which was not measured in this study. In general, it is likely that the variation in recruitment observed in our study is mediated by intra-specific competition for food (rice field) and/or refuge (fallow land), particularly during flooding of the rice fields. Mulungu et al. (2013) reported relatively higher population abundance and density values in fallow land, which may explain the low recruitment values observed in

fallow land. Thus, it is likely that the higher densities observed in fallow land lead to intense intra-specific competition and lower recruitment.

In the rice agro-ecosystem used in this study, irrigation is controlled by an irrigation scheme association, with individual farmers having little control over timing and duration of irrigation. As farmers tend to hire land within the irrigation scheme, there can be many fallow fields that remain unused, resulting in a mosaic of rice and fallow habitats. Unfortunately, the ground cover of both habitat types was not precisely measured in this study but is estimated to be around a 50% split between rice and fallow habitats. Farmers in the study area reported that 53% of farmers control rodent pests using rodenticides and 47 % use physical control, e.g. pitfall traps, kill traps, but it is not known whether these efforts have had any marked impact on rodent populations dynamics during our study. As most rodent management tends to be *ad hoc* and uncoordinated (Singleton et al., 2007), we can argue the rodent management by farmers has probably had little impact on our observations of survival and recruitment.

Although we expected the survival rate for *M. natalensis* to vary according to time, age and sex, our data did not show any significant changes in survival rates across any of these factors. Various survival models received different levels of support from the data, and the model which received the most support presented survival as a function of habitat and crop growth stage with recaptures dependent on time. One potential explanation for this is that high food resources in rice fields could increase the survival chances of newly born and older animals over the population increase phase. Results from the current study indicated that rice fields had higher survival rates than fallow land, arguably because of enhanced food quality (Mulungu et al. 2014). Previous studies have typically shown a negative relationship between the survival of *Mastomys natalensis* and rainfall (Leirs et al. 1997, Julliard et al. 1999). However, this

relationship can be complicated by density dependence and whether the population is increasing or decreasing (Sluydts et al. 2007). Our study is the first to show an association between survival of *Mastomys natalensis* and habitat type (rice or fallow field). It has been reported that when high-quality forage was available, life expectancy of prairie voles increased (Cole and Batzli 1979). It is generally accepted that animals having adequate food and proper nutrition throughout their lives grow larger and remain healthier than animals that experience poor nutrition during part or all of their lives.

Although adult survival in long-lived vertebrate species is a sensitive demographic parameter affecting population change, fecundity is usually more important in species with shorter life spans (Boyce 1992). High adult survival is a life history characteristic that is common to large mammals and vertebrates, in general, but generally not to smaller mammals, including *Mastomys natalensis*. Wildlife in good condition with higher reproduction rates are more resistant to diseases and can escape predators better than animals in poor condition (Yarrow, 2009). Nutrition affects birth and death rates and is important in the overall survival of any wild animal, and the availability of food usually varies over time (season) and space (geographic location). Observations of high survival in rice fields and particularly during the harvesting period would support the importance of food availability for adult survival. Although our study did not collect data on other factors such as disease and predation, our data would suggest that the availability of high quality food is arguably the most important parameter affecting rodent survival in rice/fallow mosaic habitats.

We have demonstrated that survival and recruitment rates of *M. natalensis* differed with crop growth stage and habitat. The lowest survival and recruitment rates were observed in fallow land which sustained higher densities of rodents, arguably leading to intense intraspecific

competition, and hence, reductions in survival and recruitment. Our results also suggest that high survival and recruitment in rice fields was related to the presence of high quality food that is preferred by *M. natalensis* (Mulungu et al. 2011). Management strategies should, therefore, be aimed at rodents inhabiting rice fields using methods that reduce recruitment and survival at transplanting and prior to rice maturity.

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References

- Albert DM and Bowyer RT (1991) Factors related to grizzly bear-human interactions in Denali National Park. *Wildlife Society Bulletin*, 19:339- 349.
- Batzli, G. 1981. Population and energetics of small mammals in the tundra ecosystem. In: Bliss, L. C., Heal, D. W. and Incore, T. J (eds.). *Tundra ecosystems: a comparative analysis*. International Biological Programme, No. 25. Cambridge Univ. Press, Cambridge. pp. 377-396
- Berryman AA (1999) *Principles of population dynamics and their application*. Stanley Thornes Publishers Ltd., Cheltenham. 243 pp.

- Borremans, B., V. Sluydts, R.H. Makundi and H. Leirs. 2014. Evaluation of short-, mid- and long-term effects of toe clipping on a wild rodent. *Wildlife Res.* <http://dx.doi.org/10.1071/WR14109>
- Boutin S (1990) Food supplementation experiments with terrestrial vertebrates: patterns, problems, and the future. *Canadian Journal of Zoology* 68:203–220.
- Boyce MS (1992) Population viability analysis. *Annual Review of Ecology and Systematics*. 23:481-506.
- Boyle SA and Samson FB (1985) Effects of non-consumptive recreation on wildlife: a review. *Wildl. Soc. Bull.* **13**: 110–116.
- Brown PR, Tuan NP, Singleton GR, Ha PTT, Hoa PT, Hue, DT, Tan TQ, Tuat NV, Jacob J, and Müller WJ (2006). Ecologically Based Management of rodents in the real world: applied to a mixed agroecosystem in Vietnam. *Ecological Applications* 16:2000–2010
- Burnham KP and Anderson DR (2002) Model selection and multimodel inference. A practical information-theoretic approach. Second edition. Springer-Verlag, New York, USA.
- Cole FR and Batzli G0 (1979) of the prairie vole, *Microtus ochrogaster*, in central Illinois. *Journal of Animal Ecology*, 48: 455-470.
- Croxall JP and Rothery P (1991) Population regulation of seabirds: implications of their demography for conservation. Pp. 272–295 in Perrins, C.M., Lebreton, J. -D. & Hiron, G. J. M. (eds.). *Bird population studies: relevance to conservation and management*. Oxford University
- Duffus DA and Dearden P (1990) Non-consumptive wildlife-oriented recreation: A conceptual framework. *Biological Conservation*, 53: 213-231.

- Erb J, Boyce MS and Stenseth NC (2001) Population dynamics of large and small mammals. *Oikos* 92:3–12.
- Hulbert IAR (1990) The response of ruddy shelduck *Tadorna ferruginea* to tourist activity in the Royal Chitwan National Park. *Biol. Conserv.* **52**: 113–123.
- Ims RA and Andreassen HP (2000) Spatial synchronization of vole population dynamics by predatory birds. *Nature* 408:194–196.
- Julliard R, Leirs H, Stenseth NC, Yoccoz NG, Prevotjulliard Karanth KU and Nichols JD (1999) Survival-variation within and between functional categories of the African Multimammate rat . *Journal of Animal Ecology*, 68(3): 550-561.
- Kennis J, C Laurent ND Amundala AM Dudu and Leirs H (2012) Survival and movement of the Congo forest mouse (*Deomys ferrugineus*): a comparison of primary rainforest and fallow land in Kisangani, Democratic Republic of Congo. *African Zoology* **47**(1): 147–159
- Kingdon J (1997) East African Mammals: An Atlas of Evolution in Africa. Vol. 2 part B (Hares and Rodents). Academic Press, London, England. 450pp
- Lebreton JD, Burnham KP, Clobert J and Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: A unified approach with case studies. *Ecological Monography* 62(1), 67–118.
- Leirs H, Stenseth NC, Nichols JD, Hines JE, Verhagen R & Verheyen W (1997) Stochastic seasonality and nonlinear density-dependent factors regulate population size in an African rodent. *Nature*, 389: 176–180
- Leirs H. (1995) Population ecology of *Mastomys natalensis* (Smith, 1834). Implications for rodent control in Africa. PhD thesis, University of Antwerp. Agricultural Edition. Belgian Administration for Development Cooperation, Brussels 35, 1-268.

- Leirs H (1992) Population ecology of *Mastomys natalensis* (Smith 1834) multimammate rats: possible implications for rodent control in Africa. PhD Thesis. University of Antwerp, Belgium.
- Leirs H, Stuyck J, Verhagen R and Verheyen W (1990) Seasonal variation in growth of *Mastomys natalensis* (Rodentia: Muridae) in Morogoro, Tanzania. *African Journal of Ecology* **28**: 298–306.
- Leirs H, Verhagen R and Verheyen W (1994) The basis of reproductive seasonality in *Mastomys* rat (Rodentia: Muridae). *Journal of Tropical Ecology* **10**(1): 55–66.
- Lima M, Julliard R, Stenseth NC and Jaksic F (2001) Demographic dynamics of a neotropical small rodent (*Phyllotis darwini*): feedback structure, predation and climatic factors. *Journal of Animal Ecology* **70**:761–775.
- Lima M, Julliard R, Stenseth NC and Jaksic FM (2003) Population dynamics of small mammals in semi-arid regions: a comparative study of within-year demographic variability in two rodent species. *Proceedings of the Royal Society, series B* **270**:1997–2007.
- Lott DF and McCoy M (1995) Asian rhinos *Rhinoceros unicornis* on the run? Impact of tourist visits on one population. *Biol. Conserv.* **73**: 23–26.
- Madsen PT, Wahlberg M, Tougaard J, Lucke K and Tyack P (2006) Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology Programme Serial 309, 279-295.
- Massawe AW, RH Makundi LS Mulungu, A Katakweba and TN Shayo (2012) Breeding dynamics of rodent species inhabiting farm-fallow mosaic fields in Central Tanzania, *African Zoology.* **47**(1): 128–137

- Massawe AW, Mulungu LS, Makundi RH, Dlamini N, Eiseb SJ, Kirsten F, Mahlaba T, Malebane P, von Maltitz E, Monadjem A, Taylor P, Tutjavi V, Belmain SR (2011) Spatial and temporal population dynamics of rodents in three geographically different regions in Africa: implication for ecologically-based rodent management. *Afr Zool.* 46:393–405.
- Massawe AW, W Rwamugira, H Leirs, RH Makundi and LS Mulungu (2005) Influence of land preparation methods and vegetation cover on population abundance of *Mastomys natalensis* in Morogoro, Tanzania. *Belgian Journal of Zoology.*, 135(Sup): 187-190.
- Meserve PL, Milstead WB, and Gutiérrez JR (2001) Results of a food addition experiment in a north-central Chile small mammal assemblage: evidence for the role of “bottom-up” factors. *Oikos* 94: 548–56.
- Mulungu LS, Mrosso FP, Katakweba AAS, Mdangi ME, Tesha PPH, Ngowo V, Mchomvu M, Kilonzo BS. (forthcoming). Farmer’s knowledge, attitude and practice on rodent management in lowland irrigated rice in Central-eastern, Tanzania. *Res J Agric Environ Manag.*
- Mulungu LS, ECM Mlyashimbi, V Ngowo, M Mdangi, AS Katakweba, P Tesha, FP Mrosso, M Mchomvu, BS Kilonzo and SR Belmain (2014) Food preferences of the Multimammate mouse, *Mastomys natalensis*, in irrigated rice habitats in Tanzania, *International Journal of Pest Management*, 60(1): 1-8
- Mulungu LS, Ngowo V, Mdangi M, Katakweba AS, Tesha P, Mrosso FP, Mchomvu M, Sheyo PM, Kilonzo BS (2013) Population dynamics and breeding patterns of Multimammate mouse, *Mastomys natalensis* (Smith 1834), in irrigated rice fields in eastern Tanzania. *Pest Manag. Sci.* 69:371–377.

- Mulungu LS, Mahlaba TA, Massawe AW, Kennis J, Crauwels D, Eiseb S, Monadjem A, Makundi RH, Katakweba AAS, Leirs H, Belmain SR (2011) Dietary differences of the multimammate mouse, *Mastomys natalensis* (Smith 1834), across different habitats and seasons in Tanzania and Swaziland. *Wildlife Research*, **38**(7): 640-646
- Pradel, R (1996) Utilization of capture-mark-recapture for the study of recruitment and population growth rate. *Biometrics*, 52:703-709
- Pollock KH, JD Nichols, JE Hines, and C Brownie (1990) Statistical inference for capture–recapture experiments. *Wildlife Monographs* 107.
- Prevot-Julliard AC, Henttonen H, Yoccoz NG and Stenseth NC (1999) Delayed maturation in female bank voles: optimal decision or social constraint? *Journal of Animal Ecology* 68:684–697.
- Sikes RS, Gannon WL, and the Animal Care and Use Committee of the American Society of Mammalogists (2011) Guidelines of the American Society of Mammalogists for the use of wild mammals in research, *Journal of Mammalogy*, 92(1):235–253
- Sluydts, V., Crespin, L., Davis, S., Lima, M. & Leirs, H. (2007) Survival and maturation rates of the African rodent, *Mastomys natalensis*: density dependence and rainfall. *Integrative Zoology*, 2: 220–232
- Telfer S, Bennett M, Bown KJ, Cavanagh R, Crespin L, Hazel S, Jones T & Begon M (2002) The effects of cowpox virus on survival in natural rodent populations: increases and decreases. *Journal of Animal Ecology* 71:558–568.
- Van Gulck T, R Stocks, R Verhagen, CA Sabuni, P Mwanjabe and H Leirs (1998) Short-term effects of Avian predation variation on population size and local survival of the Multimammate rats, *Mastomys natalensis* (Rodentia, Muridae). *Mammalia* 62: 439-339

White GC (2008) Closed population estimation models and their extensions in Program MARK.

Environ. Ecol. Stat. 15, 89-99.

White GC and Burnham KP (1999) Program MARK: survival estimation from populations of marked animals. Bird Study 46, S120–138

Yarrow G. (2009) Habitat Requirements of Wildlife: Food, Water, Cover and Space

http://www.clemson.edu/extension/natural_resources/wildlife/publications/pdfs/fs14_habitat_requirements.pdf. Visited on 15/09/2014

Table 1. Model selection for survival (Φ) and recapture (P) probabilities. The candidate models used to estimate survival in *Mastomys natalensis* in Tanzania. Estimates of survival (ϕ) and recapture (p) were modelled with time (t) and/or habitat (rice or fallow fields), cropping stage (transplanting, vegetative, booting and harvesting), and season (dry and wet). The number of parameters is indicated by “np”. The models are arranged from best (top of table) to worst (bottom). DEV = deviance?; np = number of estimable parameters; AICc = Akaike criterion of information corrected for low sample sizes; DAICc = difference in AICc from the model with the minimal score; AW = Akaike’s weight.

Model	AICc	Delta AICc	AICc Weights	np
Φ (habitat, cropping stage) P (time)	3819.75	0.00	0.77	30
Φ (habitat, time) P (time)	3829.52	3.06	0.17	65
Φ (habitat) P (time)	3837.67	11.22	0.003	24
Φ (habitat, season) P (time)	3839.06	12.61	0.001	26
Φ (constant) P (habitat, time)	3854.67	28.21	0.00	10
Φ (habitat) P (time)	332.36	11.69	0.002	18
Φ (constant) P (constant)	3941.33	114.87	0.00	3

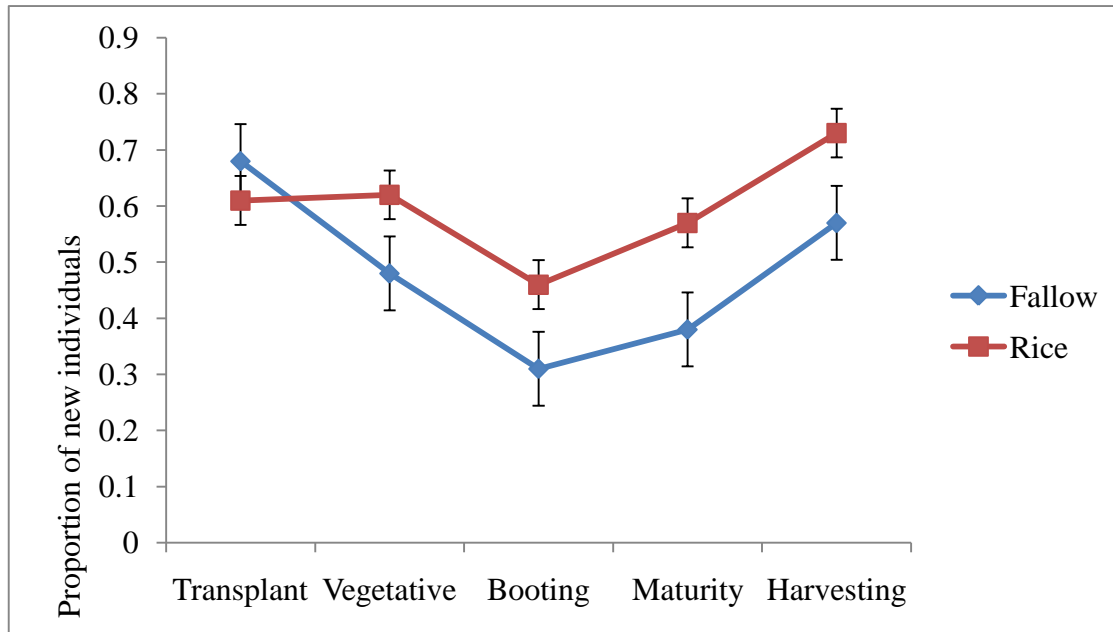


Figure 1. Proportion of new individuals entering the trappable population in the two habitats at different growth stages of rice crop

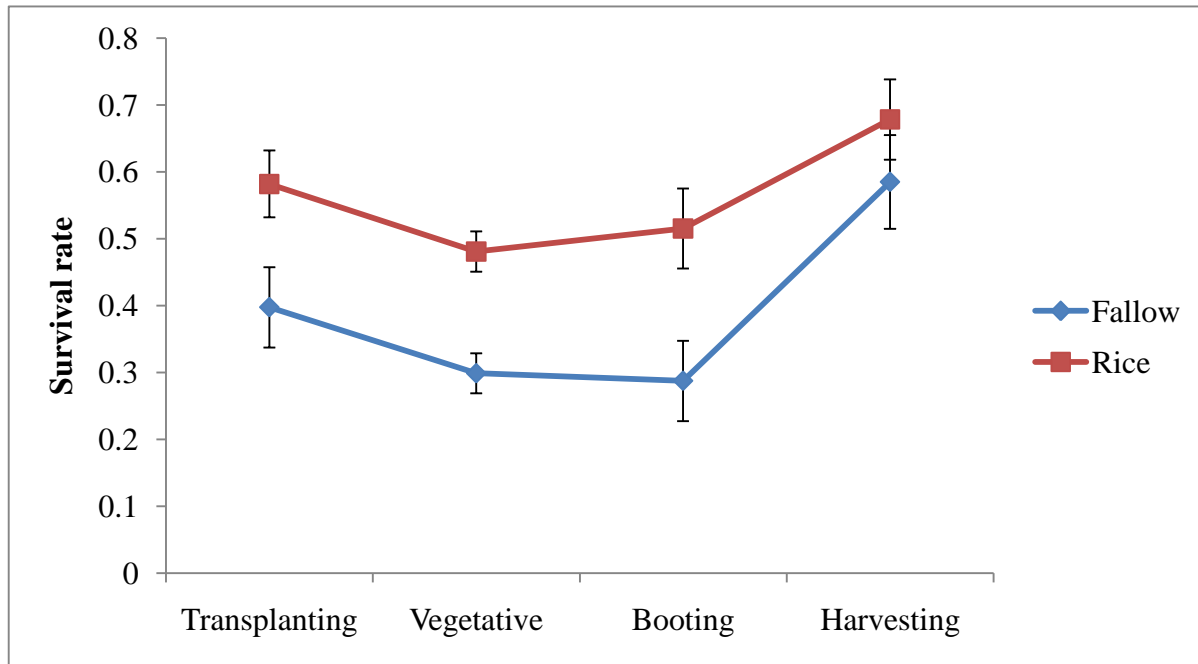


Figure 2. Survival rates (95% CI) of *Mastomys natalensis* based on the best model (see Table 1) in different habitats and cropping stages.