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A comparative assessment on rodent impacts and cultural perceptions of ecologically based rodent management in three Afro-Malagasy farming regions

Running title: Ecologically Based Rodent Management

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Abstract

Rodents generate negative consequences for smallholder farmers in Africa that directly impact household and livestock damage, food security and public health. Ecologically Based Rodent Management (EBRM) seeks sustainable solutions for the mitigation of rodent damage through assessments of rodent population dynamics, agro-ecosystems and socio-cultural contexts. We adopt a comparative approach across three rural Afro-Malagasy smallholder farming regions in South Africa, Tanzania and Madagascar to assess the household impacts of rodent pests and current perceptions and preferences associated with several rodent control measures. We conducted focus groups questionnaires and interviews in different study site locations. Rodents assert multiple impacts on Afro-Malagasy farmers demonstrating recurrent and emerging agricultural and household costs, and public health impacts. We identify a significant knowledge gap in educating communities about the application of different EBRM approaches in favour of acute poisons that are perceived to be more effective. Cultural issues and taboos also have a significant impact on the social acceptance of rodent hunting as well as biological control using indigenous predators. We advocate for an enhanced investigation of the socio-cultural beliefs associated with different rodent practices to understand the factors underlying social acceptance. A collaborative approach that integrates the perspectives of

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target communities to inform the design of EBRM initiatives according to the specific agro-ecosystem and socio-cultural context is necessary to ensure programmatic success.

Key Words: Ecologically Based Rodent Management, Crop Damage, Farmer Survey, Beliefs, Africa

1. Introduction

The African continent is home to 463 species of rodents, 77 of which damage crops and 12-20 are significant crop pests (Monadjem *et al.* 2015). For resource-poor farmers across Africa and Madagascar, rodents pose a significant threat to food security and agricultural productivity (Swanepoel *et al.* 2017b). Studies of Afro-Malagasy farming communities revealed that while estimated crop losses varied between cropping stages, the highest losses peaked during the seedling (46% median loss) and maturity stages (15% median loss) (Swanepoel *et al.* 2017b). However during pest outbreaks, crop losses for maize can reach damage levels of 80-100% (Mwanjabe & Leirs 1997, Mwanjabe *et al.* 2002). Rodents damage clothes, blankets and furniture, contaminate food stores and attack small stock (Garba *et al.* 2014). Rodents also represent threats to public health as reservoirs of zoonotic diseases including Lassa fever, plague, leptospirosis and toxoplasmosis (Duchemin & Bitam 2017, Saez *et al.* 2018). Therefore, rodents assert multiple impacts on humans including food security and public health problems across national and global scales, yet these problems are rarely explored among Afro-Malagasy communities (Ziwa *et al.* 2013, Mead 2018).

Concerns of the long-the long-term efficacy of chemical rodenticides due to resistance and secondary poisoning contributed to the development of Ecologically Based Rodent Management (EBRM) approaches (Singleton *et al.* 1999). This method aims to achieve rodent population suppression by the application of alternative forms of rodent control, using ecologically sound methods (Makundi & Massawe 2011). Mitigation of impact is achieved through assessments of rodent ecology and considering agro-ecological and socio-economic contexts (Massawe *et al.* 2012). Tools used by EBRM include habitat modification to reduce rodent key resources (Makundi *et al.* 1999), biological control, through the use of indigenous predators to limit rodent numbers (Mahlaba *et al.* 2017, Williams *et al.* 2018), and assessments of rodent ecology to explore the appropriate timing of rodent control measures through preventive action (Makundi *et al.* 1999).

Explorations of EBRM by communities experiencing problems with rodent damage are often complicated by the cost-effectiveness and social acceptance (Ninh *et al.* 2016). These factors are important to develop culturally specific approaches for rodent management. Advocates of EBRM call for increased engagement of different ethnic groups to understand how cultural factors influence the ways farmers perceive and conduct rodent management (Palis *et al.* 2013). Knowledge, attitude and perception studies have been an important component of EBRM across South-East Asia (Brown *et al.* 2008, Ngaomei & Singh 2016), and are increasing in scope across Africa (Meheretu *et al.* 2010, Mulungu *et al.* 2015), but are largely lacking in South Africa and Madagascar. An exploration of people's knowledge and perceptions of rodent damage and management may provide indirect yet insightful information for promoting EBRM in different contexts.

We adopt a comparative approach herein, drawing on different case studies among different Afro-Malagasy communities to identify cross-cutting themes to assess: (i) the multiple impacts of rodent pests, (ii) current perceptions in rodent management, and (iii) preferences of different rodent management methods. We investigate these interactions focusing on three smallholder farming regions in South Africa, Tanzania and Madagascar to compare key sites and countries, with different histories of rodent pest management. Tanzania has focused on applied rodent research and knowledge extension with respect to agricultural damage and rodent population outbreaks (Swanepoel *et al.* 2017b), whilst Madagascar has traditionally perceived rodents as a public health concern due to endemic plague (Andrianaivoarimanana *et al.* 2013) and South Africa has a more advanced private sector rodent control industry (SAPCA, 2019). Each country is experiencing growing issues with rodent pests in smallholder farming communities, yet they have contrasting agro-ecosystems, environmental and social-cultural contexts. Each case example presents the setting of each study site, specific problem focus, methods and key findings. We then discuss cross-cutting themes in relation to the impacts of rodent pests and perceptions and preferences associated with different rodent management interventions. The analysis suggests several implications for promoting EBRM among Afro-Malagasy farming communities.

2. Material and Methods

The study site centres on Afro-Malagasy smallholder farming regions in South Africa, Tanzania and Madagascar (Figure 1).

[Insert Figure 1]

Subsistence or semi-subsistence farming is practised in all cases, typically in small plots of 1 ha or less. Differences between villages, districts and countries in population size, land use types, physical geography, crops, storage methods, language, and rodent pests are summarised in Table 1.

[Insert Table 1]

Focus groups were conducted in the Vhembe/Mopani District of South Africa and the Handeni District of Tanzania from April to May 2014. Focus groups consisted of a range of gender groups, farming communities, village leaders and extension officers. A total of 18 focus groups (range: 6-13 informants) were carried out in South Africa and five focus groups in Tanzania (12 informants per focus group). Questions were posed to each group in the local language and responses were noted down and translated into English.

Firstly, questions focused on assessing rodent damage by asking farmers a series of opened ended questions (whether rodents are a problem in the community, how do they know if they are a problem, types of problems caused) followed by questions exploring the specificities of damage caused to household, livestock, human health and crops. Questions addressing crop damage asked informants to estimate the total crop damage per annum for crop species at different stages of crop development (crop fields, harvest, post-harvest and stores).

Secondly, informants were asked to identify their level of agreement toward different statements by responding either "yes,' 'no' and 'maybe.' The first series of statement explored perceptions of the effectiveness of different EBRM approaches, such as synchronising the timing of crop planting, cleaning and improving hygiene on farms, and hunting and trapping rodents. The second series of statements explored perceptions of the effectiveness of individual and community management approaches. The third series of statements identified perceptions of the effectiveness of rodenticides such as poisons and anti-coagulants.

Thirdly, questions focused on preferences for the uptake of different types of rodent management, the perceived costs of different strategies, future management approaches, the application of biological control (using cats, birds of prey, snakes and other reptiles) and perceptions toward the promotion of these approaches in their community. Each group was encouraged to discuss each of their responses, and in some cases represent collective answers. In certain cases, respondents often gave more than one answer to an individual question.

In Madagascar, two types of questionnaires were used during the interviews: (i) a household questionnaire discussed with people in their home setting and (ii) another for local women and men ranging in age from 18-60 years old as they worked in their agricultural fields. Individual questionnaires were used instead of focal groups because most people do not express personal ideas when in group settings. Data collection took place in local villages between June and July 2014 for Kianjavato and Mahasoabe and August and September 2015 for Ambatolaona, Mahatsara and Beforona. Before the interviews took place, a review of the local fokontany (single or group of nearby villages) structure was conducted to determine the number of immediate villages and households. This list of households served as the basis for the selection of households and interviewees. Questionnaires focused on the same questions for the focus group interviews in South Africa and Tanzania. The original questionnaire was written in English and translated into French and investigators used the Malagasy language to conduct interviews.

Fieldwork was approved by the Research Ethics Committees of Sokoine University of Agriculture for activities in Tanzania, University of Venda for activities in South Africa and Association Vahatra for activities in Madagascar. All qualitative data generated from focus groups and questionnaires were condensed as summary statistics based on the percentage of responses generated from informants.

3. Results

3.1 Rodent Impacts

3.1.1 Household Damage

Rodents were reported as a problem by all respondents in the Vhembe/Mopani, Handeni District and 98.2% of informants in eastern Madagascar. In the Vhembe/Mopani District, household damage was most commonly associated with damage to buildings (33.4%), food (30.0%) and personal possessions (28.3%) (Figure S1a, Supplementary Information). In the Handeni District, rodent household damage mainly targeted clothes (26.3%) and food storage (26.3%) (Figure S1b, Supplementary Information). In eastern Madagascar, reported rodent problems were most commonly associated with damage to buildings (28.4%), personal possessions (23.6%), clothes (22.9%) and crop damage (20.3%) (Figure S1c, Supplementary Information).

3.1.2 Crop Damage

In the Vhembe/Mopani District, annual crop damage in fields was greatest for maize, peanuts and bambara nuts (> 40%) (Table 2). The Handeni District, experienced similar levels of annual crop damage (> 40%) for maize, sunflowers (*Helianthus annuus*) and peanuts (Table 2). In the Handeni District, crop damage occurred throughout the planting, seedling and maturity stage for maize (Table 2).

[Insert Table 2]

In eastern Madagascar, annual crop damage at harvest was high (> 20%) for maize, rice, bambara nuts, peas, cassava, beans and fruits (Table 2). In contrast, estimated crop damages at harvest (annual kg of crop damage per household) were variable, with high damages estimated for bambara nuts (only a single response: 150 kg), compared to rice (range: 1.2-60 kg) and beans (range: 6.3-12 kg) (Table 2).

In the Vhembe/Mopani District, post-harvest crop losses were higher than reports of damage in crop fields for maize and peanuts (> 70%) and estimated crop losses in food stores were highest for maize and peanuts (> 30%) (Table 2). In the Handeni District, estimated post-harvest crop damage were high maize and sunflowers (>30%) (Table 1). In eastern Madagascar, post-harvest crop damage (annual kg of crop damage per household) was relatively low for maize (range: 3-20 kg) and cassava (range: 2-10 kg) (Table 2). Food damage in stores (annual kg of crop damage per household) was also low for bambara nuts (only a single response: 3 kg) and rice (range: 1.5-60 kg) (Table 2).

3.1.3 Livestock Damage

In the Vhembe/Mopani District, 40.9% of participants reported no rodent problems relating to livestock rodent damage to livestock (Figure 2a). Although some evidence of livestock damage was mostly evidenced through feed contamination (31.8%), attacks on chickens/and eggs (22.7%) (Figure 2a).

[Insert Figure 2a-c]

In the Handeni District, rodent damage to livestock was corroborated mainly through attacks on chickens/eggs (80.0%) and wounds to calves (20.0%) (Figure 2b). In eastern Madagascar, damage caused by rodents was commonly associated with attacks on chickens/eggs (65.4%), while 31.6% reported no livestock damage (Figure 2c).

3.1.4 Public Health

In the Vhembe/Mopani District, the majority of respondents reported no health impacts from rodents (94.1%), while 5.9% reported rodent bites (Figure 3a).

[Insert Figure 3a-c]

In the Handeni District, rodent related health problems were caused by rodent bites (41.7%), although some respondents reported knowledge of rodents spreading disease (8.3%), such as tetanus (8.3%), dysentery (8.3%), plague (8.3%), and unknown fevers (8.3%) (Figure 3b).

In eastern Madagascar, 67.2% of informants reported no health impacts (Figure 3c). However, some health impacts mentioned by informants were associated with unknown fevers (25.2%), fleas (2.3%), contaminated food (2.0%) and water (1.2%), coughs (0.4%), insomnia (0.4%), scabies (0.4%) and unspecified diseases (0.2%) (Figure 3c).

3.2 Current Perceptions in Rodent Management

3.2.1 EBRM Approaches

Over half of the across all case studies (Vhembe/Mopani District: 50%, Handeni District: 100% and eastern Madagascar: 55.5%) disagreed that synchronous planting of crops can reduce rodent populations (Figure 4a).

[Insert Figure 4a-c]

The majority of farming communities in the Vhembe/Mopani District (55.6%) and eastern Madagascar (65.6%) supported the view that improving cleanliness on farms and surrounding areas can reduce rodent populations, while in the Handeni District, even numbers of people either supported (40%) or were against this view (40%) (Figure 4a). In the Vhembe/Mopani District (72.2%) and eastern Madagascar (48.4%) of informants disagreed that hunting reduces the severity of their damage, while all informants in the Handeni District "maybe" agreed with this statement (Figure 4a). Similarly, the majority of informants in the Vhembe/Mopani District (72.2%) and eastern Madagascar (61.0%) supported the view that trapping reduces the severity of rodent damage, while in the Handeni District 40% agreed with this statement (Figure 4a).

3.2.2 Individual and Community Rodent Management

In eastern Madagascar, 61.2% of informants supported the view that individual rodent control is best to control their damage, while the majority of informants in the Vhembe/Mopani District (100%) and Handeni District (66.7%), disagreed with this statement (Figure 4b). The majority of informants across the case studies agreed rodent management must be done continuously in order to be effective and community rodent control at any time during the cropping season is most effective (Figure 4b). The majority of farmers in the Handeni District (100%) and eastern Madagascar (69.9%) supported the view that community rodent control at a specific stage of crop growth is most effective (Figure 4b). In contrast, 58.8% of informants disagreed with this statement in the Vhembe/Mopani District (Figure 4b).

3.2.3 Rodenticides

The majority of informants across the Afro-Malagasy study regions agreed that rodenticides reduces the severity of observed rodent damage (Figure 4c). In the Vhembe/Mopani District, all informants agreed that acute poisons were "maybe" effective and safe to use, while in the Handeni District 100% disagreed with this statement (Figure 4c). In the Vhembe/Mopani District equal numbers of respondents supported (44.4%) and were against (44.4%) the view use that anticoagulants are an effective and safe poison to use, while 60% of informants in the Handeni District "maybe' agreed with this statement (Figure 4c).

3.3 Preferences for Rodent Control

3.3.1 Uptake of Rodent Control Measures

In the Vhembe/Handeni District, popular methods for rodent control in crop fields and households included acute poison (34.6%) and chronic poison (23.1%), which were all cited as effective and cheap management approaches (Figure S5a and Table S1, Supplementary Information).

[Insert Figure 5a-c]

In the Handeni District, acute poison (50.0%) and the non-steroidal anti-inflammatory drug Indomethacin (30.0%) were popular forms of rodent control (Figure 5b). Local support for acute poisons such as zinc phosphide were attributed to fast-acting results and applications were preferred in food stores and homesteads as opposed to crop fields (Table S1, Supplementary Information). The economic costs of using acute poison and Indomethacin were perceived as low; justifying their widespread use (Table S1, Supplementary Information). In eastern Madagascar, snap traps (27.6%), granaries (17.4%) and cats (16.3%) were popular forms of rodent control (Figure 5c) owing to their cost-effectiveness (Table S1, Supplementary Information).

The majority of community members in the Vhembe/Mopani District stated they would continue to snap traps (43.4%), anticoagulants (e.g. Rattex) (34.9%), followed by poison (e.g. Aldicarb) (17.4%) to manage rodent problems in the future because they were cheap and effective (Figure S2a, Supplementary Information). In the Handeni District 83.3% and 16.7% of informants supported the continued future use of poisons and Indomethacin, respectively (Figure S2b, Supplementary Information). In eastern Madagascar, cats (25.1%) and rodenticides (24.2%) were cited as the most popular forms of rodent control for continued use in the future (Figure S2c, Supplementary Information).

3.3.2 Biological Control

The majority of informants across Afro-Malagasy farming communities believed that cats were effective in controlling rodent problems in their villages (Figure 6).

[Insert Figure 6]

In the Handeni District and eastern Madagascar, 83.3% and 61.0%, respectively, of respondents believed that owls, snakes and other animals were effective in controlling rodent numbers (Figure 6). However, in the Vhembe/Mopani District, 76.0% of respondents believed that owls, snakes and other animals were ineffective (Figure 6). The presence of snakes and owls was discouraged because of a fear of snakes and beliefs associated with owls such as witchcraft and bringing “evil to the village.” Informants who supported the use of cats to control rodents, did not tolerate the presence of other predators such as snakes and owls. Common informant statements included: “we will not tolerate other animals, other than cats” and “yes to cats, no to snakes and owls.”

In the Vhembe/Mopani District and eastern Madagascar, 100% and 85.5%, respectively, of community members were against the promotion of using indigenous predators for rodent control, stating that the presence of these animals was ineffective against rodents (Figure 6). In contrast, a high percentage of community members (62.5%) in the Handeni District supported the promotion of indigenous predators for rodent control (Figure 6). Those against the use of biological control methods indicated that local beliefs and the perception of snakes as dangerous animals prohibited them from supporting these strategies.

4. Discussion

4.1 Rodent Impacts

Rodent-induced problems are uniformly significant and widespread across Afro-Malagasy farming regions, causing household, crop and livestock damage and public health threats.

4.1.1 Crop Damage

In all countries, rodent damage to crops (pre- and post-harvest) was perceived to be of considerable importance. In terms of crop damage our study revealed the importance of understanding the specificities of the agro-ecosystem and cropping systems to inform effective EBRM at local scales. For example, EBRM approaches should focus on cropping systems of high economic value such as maize (South Africa and Tanzania) and rice (eastern Madagascar) where socio-economic losses due to rodent damage are perceived to be especially high. Annual crop yields for smallholder maize farmers in the Limpopo Province of South Africa have been estimated at 320-1600 kg/ha/yr (Rootman & Stevens 2016). In light of these figures, our reported estimates of 80% losses for maize can constitute between 256-1280 kg/ha/yr. In the Tanga region of Tanzania, crop yields for maize have been estimated at 604-1500 kg/ha/yr (Kaliba *et al.* 1998, URT, 2007) therefore, reported losses can represent half (30-750 kg/ha/yr) or a total loss of all crop yields. High crop damage for maize (> 80%), has also been documented from field trials in Tanzania (Mwanjabe & Leirs 1997, Mwanjabe *et al.* 2002), confirming our results.

Conclusions based on estimates of crop damage at different stages (in the field, at harvest and post-harvest and in stores) obtained from farmers in our study generally concur well with conclusions based on estimates from published field trials (Table S2 based on the review of Swanepoel et al. 2017b, Supplementary Information). For example, greatest losses of maize due to rodents occur at the seedling stage (Myllymaki 1989, Mulungu *et al.* 2007), while losses of rice tend to be highest at the maturity stage of rice. EBRM should be focussed on the most vulnerable stages for each crop type and region. Post-harvest estimated losses to rodents were high but variable across all countries, although actual losses reported in Madagascar (1.5-60kg/ha/yr) appeared under-estimated compared to values published for smallholder rice farmers in eastern Madagascar (Hume 2006; 1500-3000 kg/ha/yr). In all countries, polypropylene sacks are used to reduce storage maize and rice losses (Duplantier & Duchemin 2003, Leclerc-Madlala & Janowski 2004, Shabani *et al.* 2015).

4.1.2 Rodent-Borne Diseases

Rodent-borne zoonoses are common in Africa, including a number of communicable and infectious viruses, bacteria, helminths and protozoa (Meerburg *et al.* 2009). Compared to a low knowledge and perception of rodent-borne diseases in South Africa revealed by our study, an enhanced awareness of rodent borne diseases in Tanzania and Madagascar may be attributed to a history of public health and rodent control campaigns implemented and contemporary problems with endemic plague, which can cause public health emergencies in these countries (Duplantier & Rakotondravony 1999, Makundi *et al.* 2015). The seasonal epidemiology of plague in Madagascar has led to annual outbreaks for the last 30 years however, plague has been a problem in Madagascar and Tanzania for over 100 years (Mead 2018). The symptoms of illness mentioned by communities would suggest that rickettsial and leptospiral infections are important health issues in Tanzania and Madagascar and several prevalence studies support these community reports (Key 1990, Crump *et al.* 2013).

4.2 Current Perceptions in Rodent Management

The study explored local perceptions of several EBRM approaches as alternatives to rodenticides. In some cases, community perceptions reflected lack of uptake of research results. e.g. while most communities did not agree, research has demonstrated that synchronised planting may limit rodent damage for cereals, such as maize (Makundi *et al.* 2010). Synchronising planting may maximise the length of the fallow period causing rodent and populations to decrease because of a lack of food and shelter and a reduction in the duration of the breeding season (Leung *et al.* 1999). On the other hand, our surveys showed good awareness among all Afro-Malagasy communities sampled, of the importance of sanitation programmes for rodent control as confirmed by research undertaken in Africa (Makundi *et al.* 1999, Taylor *et al.* 2008). The promotion of other land use practices that may lead to the removal of rodent habitats may also be important. In Tanzania and Madagascar, where farmers practice slash and burn techniques after harvest or before planting maize crops, this temporarily clears food sources and shelter for rodents and can act as important strategy for managing habitats that support high numbers of rodents (Duplantier & Rakotondravony 1999). In Madagascar, rodent abundance is lower in dry farming areas that provide food for rodents for short periods of time and the plots are often burned once per year (Duplantier & Rakotondravony 1999). Therefore, a combination of crop synchrony coupled with productive land use management and sanitation programmes may be useful in all the case study regions to reduce the availability of food resources for rodents.

Although results were mixed, in Tanzania informants generally endorsed the use of trapping to control rodents. Some countries, such as Madagascar have a history of trapping campaigns implemented by plant protection technicians to enhance local awareness and action on the ground (Duplantier & Rakotondravony 1999). Trapping of rodents at the household level is appropriate in rural agricultural settings particularly in our case study regions, where farmers lack other adequate resources for rodent control (Makundi *et al.* 1999, Taylor *et al.* 2008). Hunting has also been suggested as one of many approaches to tackle rodent populations particularly in South-East Asia where rodents have been hunted through collective action by targeting rodent burrow systems or government bounty campaigns (Singleton *et al.* 2007). Hunting was perceived as ineffective in reducing the severity of observed rodent damage in South Africa and eastern Madagascar, while in Tanzania all informants stated hunting “maybe” reduces rodent damage. The lack of support for hunting in some of the study regions may in part be explained by cultural beliefs and prohibitions that constrain social acceptance of the hunting of animals for food. During focus groups discussions in Tanzania, those against hunting were largely Muslims who explained that hunting is usually not undertaken by local people, because it is associated with food consumption and Islamic beliefs prohibit people from eating rodent meat. Similarly, in eastern Madagascar, the hunting of rodents for food is considered dirty, disgusting and taboo; this conclusion is supported by data from the North-East (Borgerson 2015).

Although individual rodent control was preferred among smallholder farmers in eastern Madagascar, our findings demonstrate a uniform support for community rodent control measures across the Afro-Malagasy farming regions that would provide a strong foundation for engaging such groups in collective action and cultivating a shared sense of responsibility for EBRM. Coordinated community methods for EBRM have been encouraged to increase the efficacy of rodent control compared to individual approaches because labour efforts are shared across larger-scales (Palis *et al.* 2011). Some African cultures, such as the Vhavenda in the Vhembe District, have a strong history of community participation in agricultural activities; for example, clearing, weeding and harvesting of crops were often completed in semi-communal labour groups (Stayt 2018). Coordinated community methods for rodent control can help reduce rodent population growth through breeding or immigration if done continuously (Belmain *et al.* 2015). Similarly, synchronising control methods over relatively short periods of time at key periods, such as the onset of breeding, can also be effective, but this requires a detailed understanding of rodent population dynamics within particular agro-ecosystems (Brown & Khamphoukeo 2007).

4. 3 Preferences for Rodent Control

Although all countries endorsed rodenticides, Tanzania and South Africa preferred acute rodenticides, while Madagascar preferred a wider variety of options, raising concerns of ethical application. The widespread application of rodenticides across Afro-Malagasy farming regions is linked to their historical use, private sector promotion and government interventions, such as the free or subsidised distribution of rodenticides (Makundi *et al.* 1999). The preference for cheaper and faster-acting rodenticides which have negative environmental effects in terms of the risk of non-target species mortality poses a challenge for EBRM, requiring concerted educational programmes across all countries.

Biological control of rodents using domestic and indigenous predators such as cats, dogs, raptors and reptiles has garnered increasing research interest in Africa. Recent studies have demonstrated that the dual presence of cats and dogs in homesteads can reduce rodent activity, creating a 'landscape of fear' among foraging rodents (Mahlaba *et al.* 2017). Some studies have explored the potential positive impacts of using nest boxes and perches to encourage owls and other avian predators into agricultural landscapes to reduce rodent numbers (Labuschagne *et al.* 2016). The feasibility of employing biological control measures for EBRM is dependent on the social acceptance of these species. Across the study regions, there was a consensus that domestic cats were an effective measure for controlling rodent pests and were socially acceptable owing to their familiarity as domestic animals. However, birds of prey and reptile predators were perceived as ineffective in South Africa and effective in Tanzania and Madagascar. Only rural farmers in Tanzania demonstrated a willingness to promote biological control measures in their community compared to South Africa and Madagascar. Lack of support for the implementation of avian and reptilian predators for EBRM was linked to negative perceptions of snakes as dangerous because they provide ecosystem disservices, harmful to human health. Among the Vhavenda in South Africa, owls are believed to possess supernatural messages such as predicting sickness and through their association with witches' familiars (Mabogo 1990). Historically in all countries, witchcraft has been recognised by the state through law and through state practices that officialise witch-hunting (Ellis 2002, Kohnert 2003, Mesaki 2009). A belief in the magical properties of animals and occult practices that harness the harmful properties of magical creatures, such as witches using snakes to attack their victims (Bjerke 1969) have led to their persecution in Tanzania (Holmes *et al.* 2018). Among the Zigua of Tanzania, snakes are represented as metaphors for addressing changes in ways of life deemed negatively by the Zigua through discussions of the country's history of the slave trade and colonisation (Walz 2016). In certain Malagasy cultural groups certain animal species are entwined with local taboos, known locally as "*fady*". Negative taboos linked to snakes resulted in their frequent killing (Holmes *et al.* 2018). Our findings point to the importance of understanding historical and cultural beliefs that may influence social acceptance of EBRM approaches particularly, those involving taboo animals.

5. Conclusion

Our study shows that a wide range of significant rodent impacts are universally experienced at household, agricultural and public health levels across smallholder communities in South Africa, Tanzania and Madagascar. The scale of these impacts, especially to farmers, and the vulnerable stages of major cropping systems revealed by our study, is borne out by available field studies in Africa (Table S2 summarised by Swanepoel *et al*. 2017b, Supplementary Information). When it comes to awareness and implementing of EBRM, uptake by communities may vary between countries. For example, government programmes about frequent plague outbreaks have led to greater awareness of diseases risks of rodents in Madagascar and Tanzania compared to South Africa. Cultural issues and social taboos also have a significant impact, e.g. on acceptance of hunting of rodents as well as biological control by encouraging species such as owls and snakes. We identify a large gap in educating communities about the use of more environmentally acceptable, second generation rodenticides in favour of fast-acting acute poisons that are perceived to be more effective.

In conclusion the promotion of EBRM requires a more nuanced and targeted assessment of the cost-effectiveness, social acceptance and ecological specificity when appraising rodent control measures in different contexts. Secondly, identifying factors that enable or constrain decisions for the uptake of different EBRM strategies is critical for developing culturally appropriate interventions to enhance tolerance among target communities. Researchers also need understand local socio-cultural beliefs associated with different rodent practices that may enable or hinder EBRM uptake before project implementation. Thirdly, enhancing knowledge of the sustainability and appropriate application of different EBRM measures will require a multifaceted approach, where education initiatives to address knowledge gaps are designed to be culturally sensitive in accordance with the context of the target community and coupled with scientific and local knowledge of rodent and predator population dynamics. Finally, implementing EBRM requires a shift towards participatory planning processes that integrate the perceptions and concerns of local people, practitioners and policy makers to advocate for more sustainable and coordinated approaches.

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Table 1 Summary of site-specific information on each study site in South Africa, Tanzania and Madagascar

	South Africa		**Tanzania**	**Madagascar**		
District/Province	**Vhembe District**	**Mopani District**	**Handeni District**	**Fianarantsoa Province**	**Antananarivo Province**	**Toamasina Province**
Target villages (population sizes)	Vyeboom (3,579)	Ka-Ndengeza (5,026)	Kwamsisi (5,013), Magamba (3,186), Kwachaga (3,062), Suwa (6,592), and Mazingara (6,402)	Mahasoabe (34,000) and Kianjavato (5,000)	Ambatolaona (5,000) and Mahatsara (2,000)	Beforona (13,000)
Language/culture	Tshivenda	Xitsonga	Kiswahili is spoken by 54% (URT, 2016), belonging to the Zigua ethic group, the majority of which are Muslims	Principally Malagasy dialects and secondarily French are spoken. Ethnic groups include Betsileo, Tanala, Merina, Bezanozano, Vakinakarata, Betsimisaraka, Sakalava and Antaisaka.		
Elevation	700 m	580 m	581 m	190-1100 m	600-2600 m	0-1500 m
Rainfall (pa) **Wet Season** **Dry Season**	700-800 mm October - March May-August		800-1500 mm (Lower altitudes of Handeni), 400 mm (North Pare Mts) October -	1370 mm December-April July-December	1317 mm November-March April-October	3246 mm February–April September -

		December & March - June July - September			November
Natural ecosystems	Granite Lowveld and Gravelotte Rocky Bushveld	Semi deciduous Miombo Forest of the Zambezian Centre of endemism and the undifferentiated forests of the Zanzibar-Inhambane regional mosaic	Humid forest in Central Highlands dominated by *Weinmannia* (Cunoniaceae) and *Tambourissa* (Monimiaceae)	Middle- altitude dense rain forest with dominant tree genera, *Tambourissa*, *Weinmannia*, *Symphonia, Dalbergia* and *Vernonia*	Coastal Rainforest.
Land Use Types	Cropping area, communal grazing land and human settlement	Cropping area, human settlements and degraded forest areas from agriculture, firewood and timber harvesting	Agricultural land and forested patches transformed from slash and burn practices and irrigated and rainfed upland rice cultivation with some dry crop fields.		
Storage methods	Polypropylene bags in bedrooms or other secure areas of the house	Maize grains are stored in the roof of houses in polypropylene bags and used for cooking or selling	Rice either stored in granaries with difficult access for rodents and polypropylene bags stored in houses.		
Main crops	Maize (*Zea mays*) and bambara nuts (*Vigna subterranea*) are dominant, but also pumpkins (*Curcurbita* spp.), peanuts (*Arachis hypogaea*) and beans (*Phaseolus vulgaris*)	Maize, cassava (*Manihot esculenta*), beans, peanuts, banana (*Musa* spp.), sugar cane (*Saccharum* spp.) and different types	Rice (*Oryza glaberrima*) from irrigated rice valleys and rain-fed uplands associated with slash-and-burn agriculture	Ambatolaona: irrigated rice; Mahatsara: irrigated and upland rice	Beforona: irrigated and upland rice

		of vegetables.	in areas of cleared forest or reclaimed secondary habitats. Other common food plants cultivated in these areas include cassava, peanuts, maize, sweet potato (*Ipomoea batatas*) and beans		
Main rodent pests	Rats (*Rattus rattus, R. norvegicus*, *R. tanezumi*), multimammate mice (*Mastomys. coucha*, *M. natalensis*) and gerbils (*Gerbilliscus brantsii*, *G. leucogaster*)	Natal multimammate mouse (*M. natalensis*), African grass rat (*Arvicanthis neumanni*)	Rats (*R. rattus*, *R. norvegicus*) and house mouse (*Mus musculus*)		

Table 2 Summary of estimates of crop damage by rodents for households in South Africa, Tanzania and Madagascar per annum

	Species	**Crop damage in fields/% total crop damage per household**	**Crop damage at harvest/% total crop damage per household**	**Post-harvest crop damage/% total crop damage per household**	**Crop damage in stores/% total crop damage per household**
South Africa					
	Maize	Mean: 49% (Range: 40-60%)	-	Single Response: 80%	Mean: 49% (Range: 20-70%)

	Peanuts	Single response: 55%	-	Mean: 73% (Range: 70-80%)	Mean: 46% (Range 30-55%)
	Bambara nuts	Mean: 47% (Range: 40-50%)	-	-	-
	Beans	-	-	Mean: 73% (Range: 70-85%)	-
Tanzania					
	Maize	Range: 50-100%	At Planting (Range: 50-100%), Seedling (Range: 10-20%) and Maturity (Range: 10-40%)	Stored Grains (Range: 30-60%)	Range: 30-50%
	Sunflowers	Single response: 60%	At Planting: Single response 10%	Sunflowers Whole Seed: Range: 30-80%	Range: 50-60%
	Peanuts	Single response: 40%	At Maturity: Single Response 20%	Single Response: 40%	-
	Cowpeas	-	At Maturity: 20%	-	-
Madagascar					
	Maize	-	Mean: 53% (Range: 30-80%)	Mean: 11.5kg (Range: 3-20 kg)	-
	Rice	-	Mean: 38% (Range: 20-100%); Mean: 13 kg (Range 1.2-60 kg)	-	Mean: 13.3kg (Range: 1.5-60 kg)
	Bambara nuts	-	(Mean: 33% (Range: 25-50%); One Response: 150 kg	-	Single Response: 3 kg

	Peas	-	Single Response: 33%	-	-
	Cassava	-	Single Response 25%	Mean: 8kg (Range 2-10 kg)	-
	Beans	-	Single Response: 75%; Mean: 6.3 kg (Range 6.3-12 kg)	-	-
	Fruits	-	Single Response: 33%	-	-

Figure Titles

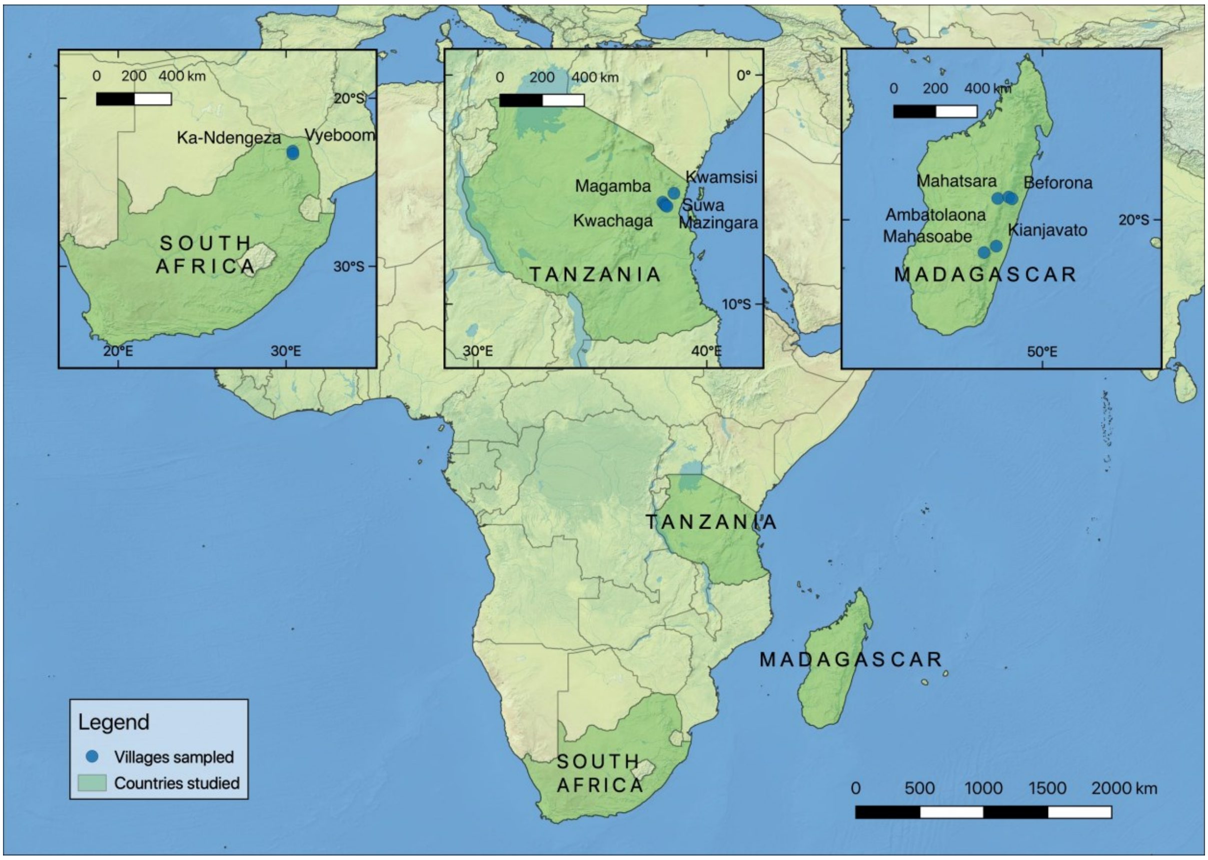


Figure 1 Map showing the locations of the study sites in South Africa, Tanzania and Madagascar.

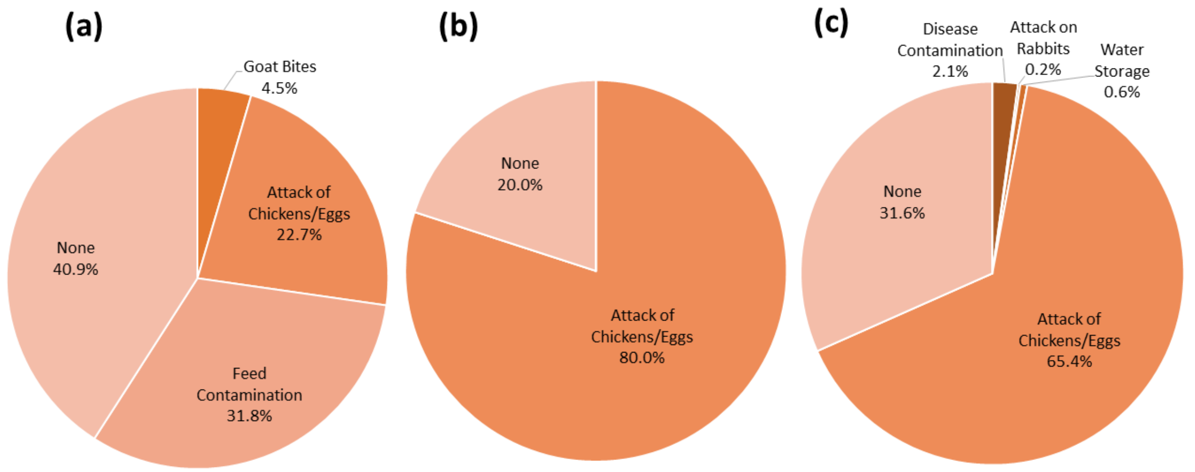


Figure 2 Percentage of responses reporting livestock damage caused by rodents in the (a) Vhembe/Mopani District of South Africa (n = 22), (b) Handeni District of Tanzania (n = 5) and (c) eastern Madagascar (n = 512).

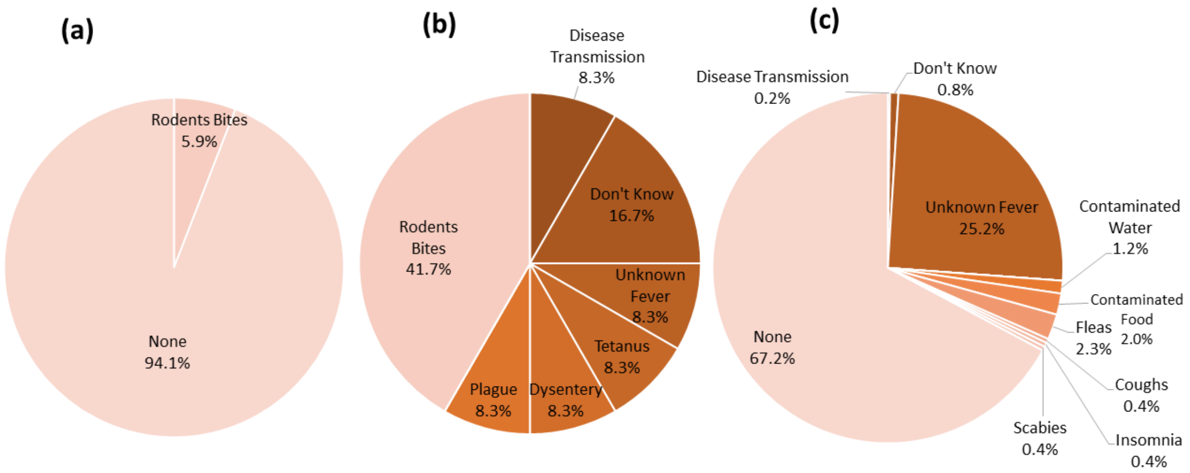
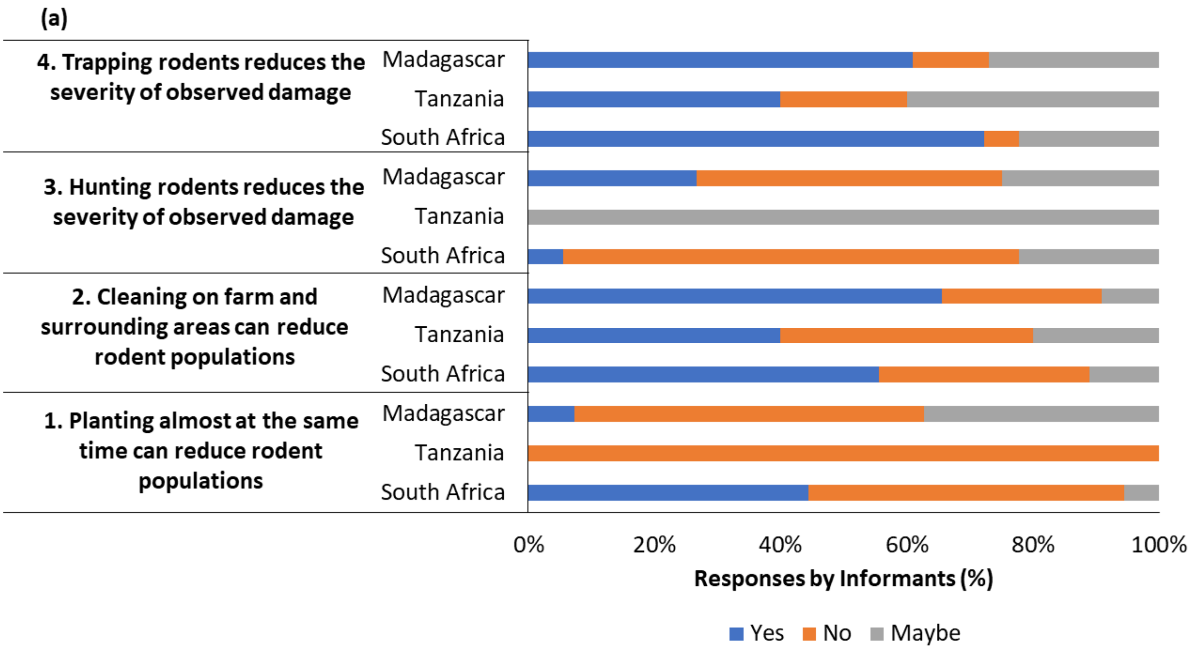
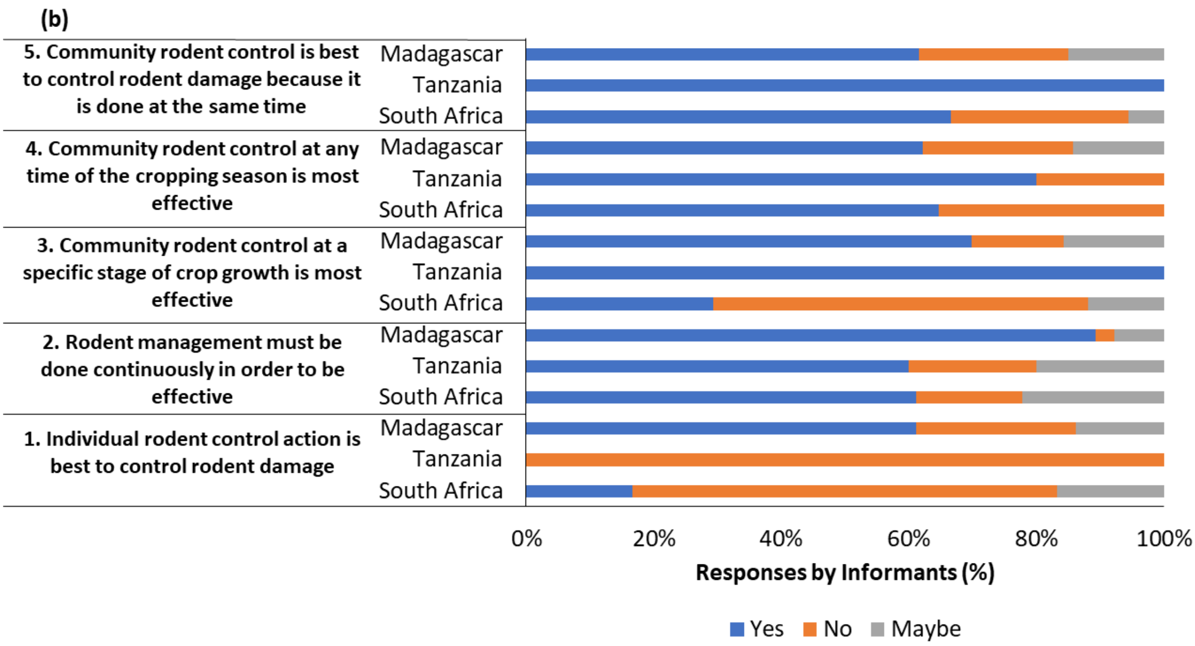


Figure 3 Percentage of responses reporting public health impacts caused by rodents in the (a) Vhembe/Mopani District of South Africa (n = 17), (b) Handeni District of Tanzania (n = 12) and (c) eastern Madagascar (n = 512).





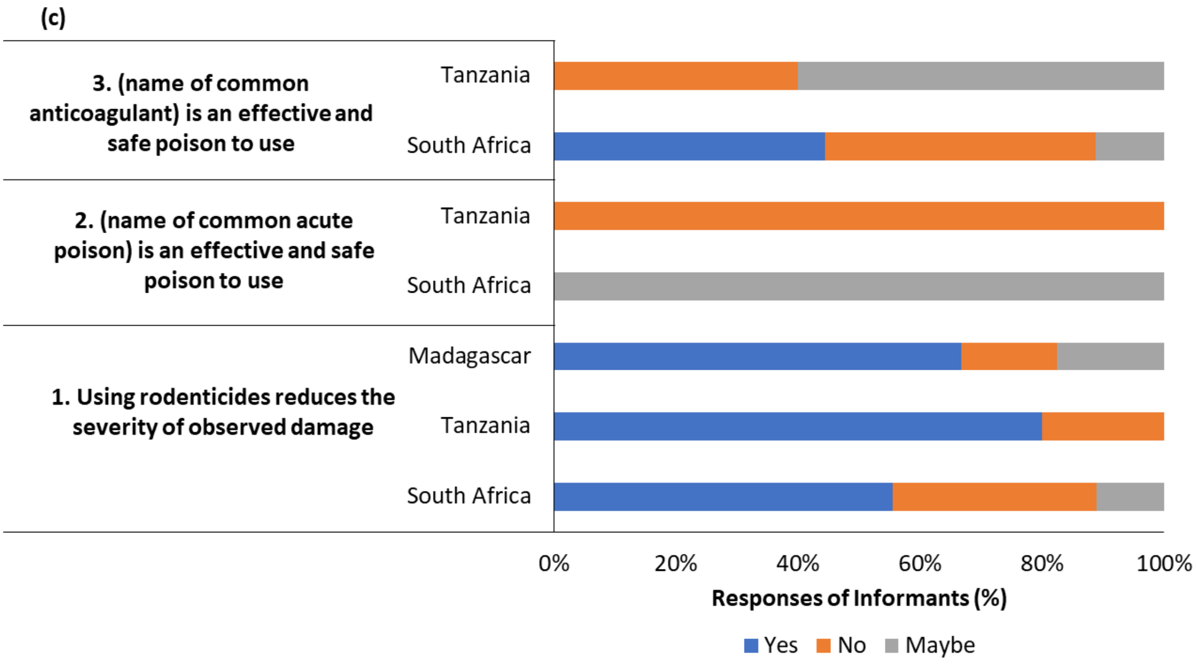


Figure 4 Percentage of responses across the Vhembe/Mopani District of South Africa (n = 18), Handeni District of Tanzania (n = 5) and (c) eastern Madagascar (n = 508) demonstrating perceptions of (a) EBRM approaches, (b) individual and community rodent management and (c) rodenticides.

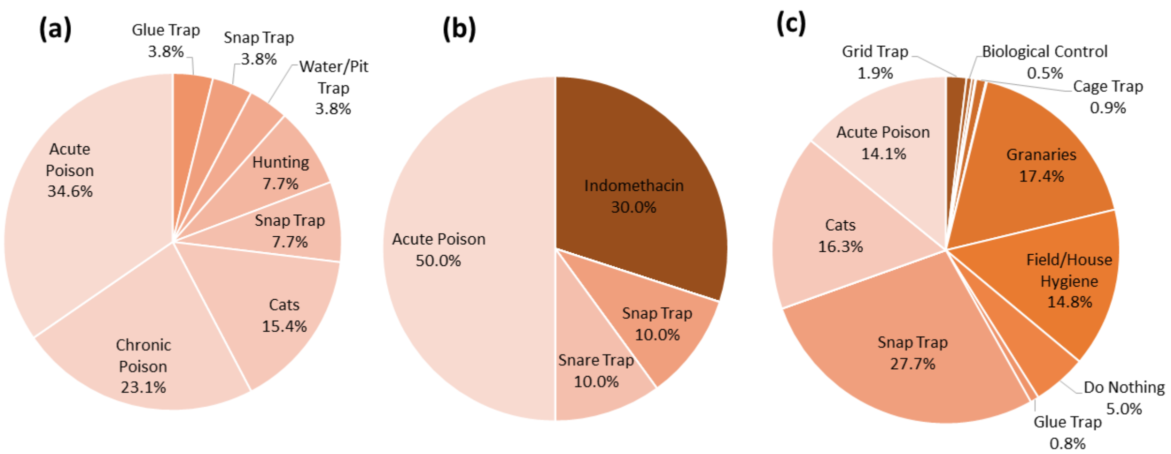


Figure 5 Percentage of responses supporting the application of different control methods for rodent management in the (a) Vhembe/Mopani District of South Africa (n = 16), (b) Handeni District of Tanzania (n = 10) and (c) eastern Madagascar (n = 786).

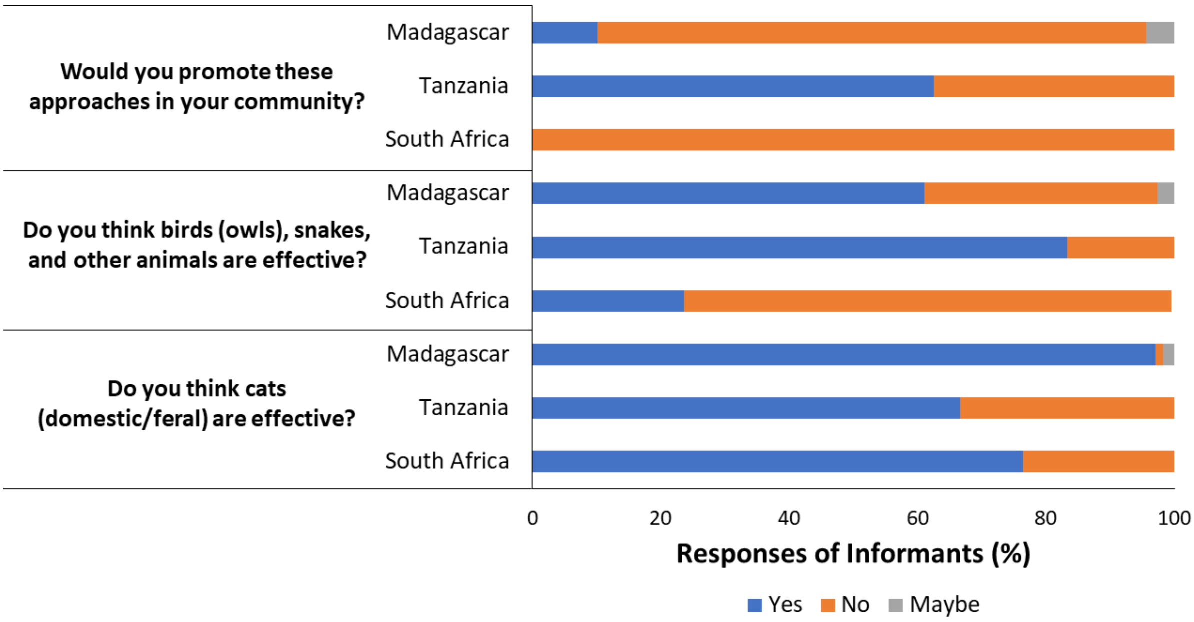


Figure 6 Percentage of responses supporting the effectiveness of cats in the Vhembe/Mopani District of South Africa (n = 17), Handeni District of Tanzania (n = 12) and eastern Madagascar (n = 508); the effectiveness of birds (owls), snakes and other animals in the Vhembe/Mopani District of South Africa (n = 17), Handeni District of Tanzania (n = 12) and eastern Madagascar (n = 498); and the promotion of these approaches in their communities in the Vhembe/Mopani District of South Africa (n = 16), Handeni District of Tanzania (n = 16), and eastern Madagascar (n = 447).