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Full Length Research Paper

Inventory of termite species in thickly vegetated region of Northeastern Puducherry, India

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A systematic survey of termite species in Northeastern Puducherry which is part of peninsular India, was carried out. As there is no pre-existing report on the richness or diversity of termifauna in this region, the present work aims to fill this major knowledge gap. The findings are discussed in the context of the quantitative studies on termifauna carried out across the world, as also in terms of the defining traits of the species identified in the survey *vis a vis* their possible use in biodegrading ligninous biowaste. The latter aspect is particularly relevant to the controlled use of termites by the process named 'termigradation', which denotes termite-based biodegradation of waste.

Key words: Termites, termigradation, indices, India, Puducherry.

INTRODUCTION

Among the nature's scavengers and earth-movers, termites play the most dominant role alongside ants and earthworms. But while the other two are very efficient in assisting in decomposition of non-ligninous organic matter, termites are capable of processing lignin as well. Abbasi and coworkers (Abbasi et al., 2007; Ganesh, 2008; Kaur, 2014; Anantharaju, 2016) have developed processes with which termites could be used in a controlled fashion to treat ligninous and other hard-to-degrade solid bio-waste. The word 'termigradation' was coined by these authors to denote termite-assisted degradation of waste (Abbasi and Gajalakshmi, 2015). To ensure that use of termigradation does not lead to the introduction of invasives, it is necessary to identify the species already established in a given region and develop a repertoire of such species and the types of waste they prefer to feed on. Till now, little quantitative information on the richness and diversity of termifauna of India is available. There exists a lot of information, of which a good part has been compiled by the Zoological Survey of India (Kaur et al., 2013; Harit et al., 2013), on species available in different regions of India and on ways to control them but much less is available, if any, in the form of quantified measures of species richness, diversity, prevalence, etc.

Moreover, most of the termite species surveys reported in India so far have been based on sampling of the animals and where the surveyors spotted them. The usual practice has been to collect the animals, where they are seen present in good number, by sweeping them into a container by very soft alcohol-moistened brush, and identify the species (Pardeshi et al., 2010, Kumar

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and Thakur, 2010). There have also been studies wherein the entire termite colonies (mounds) have been excavated and the animals enumerated (Gupta, 1953). These studies are very useful in their context which was essentially termite control/eradication but have little use in the study of beneficial aspects of termite. As these surveys have not been based on properly randomized and representative methods of sampling and enumeration, the findings are not amenable to quantification of species richness, diversity, or evenness as truly representing any study area. This also precludes a proper comparison across regions because of the subjective nature of the surveys.

Despite a general consensus among ecologists of the importance of termites, considerable knowledge gap exists on the functional roles of different termite taxa and the significance of termite diversity to soil function. Most of the published data on termite species richness and population density is not only location-specific but is difficult to generalize because different studies have used different sampling methods and experimental designs (Kaur et al., 2013, 2014). As a part of the efforts to cover the existing knowledge-gap, a systematic survey of termite species in Northeastern Puducherry which is the area where the authors are located, was carried out.

METHODS

Study area

The study was conducted at Pondicherry University campus, located in the Northeastern Puducherry. An authentic map of the campus was obtained from the Engineering wing of the University. It is to a 1:3000 scale and represents an area of 780 acres harbouring rich tropical floral (537 species) and faunal diversity (197 species) (Parthasarathy et al., 2010; PriyaDavidar et al., 2010). The most diverse plant families in the campus include Euphorbiaceae (32 species), Poaceae (28 species), Rubiaceae (26 species), Mimosaceae (24 species), Papilionaceae (23 species), Acanthaceae (21 species), Araceae (18 species), and Agavaceae, Apocynaceae and Arecaceae (16 species each). Herbs are the most diverse: 94 species (36%), followed by trees - 73 species (28%), lianas - 26 species (10%), grasses and sedges - 26 species (10%), herbaceous climbers - 23 (9%) and shrubs - 16 species (6%) (Parthasarathy et al., 2010).

The termite survey experiments was based on methods employing transects and quadrats (Jones and Eggleton, 2000). Each of these has been extensively used in faunal surveys and yields data that can be resolved into indices. In the present study, Shannon-Weiner Index and Simpson Index of diversity and Pielou's eveness index were calculated as follows (Hill, 1973; Bibi and Ali, 2013):

$$H = -\sum_{i=1}^{s} (Pi * \ln Pi)$$

Where, H'is the Shannon diversity index; Pi is the fraction of the entire population madeup of species i (proportion of a species I relative to total number of species present, not encountered); S is the numbers of species encountered and

$$D = 1-\{\Sigma n (n-1) / N (N-1)\}$$

where n is the total number of organisms of a particular species, and N is the total number of organisms of all species. The evenness was computed by Pielou's evenness index, which is denoted by:

$$J' = \frac{H'}{H'_{\max}}$$

Where H' is the number derived from the Shannon diversity index; H'max is the maximum value of H' which is given by:

$$H'_{\max} = -\sum_{i=1}^{s} \frac{1}{s} In \frac{1}{s} = In\ S$$

A protocol described by Jones and Eggleton (2000), adapted from a similar method developed by Eggleton et al. (1996), was used for the survey. The protocol has been used in many tropical forests around the world (Gathorne-Hardy et al., 2002; Davies et al., 2003). Transect of 100 m length and 2 m width, was marked and divided into 20 contiguous sections (each 5 × 2 m) and numbered sequentially. Sampling was done in each section for 30 min (a total of one hour of collecting per section). In each section, microhabitats were searched for termites: 12 samples of surface soil (each 12 × 12, to 10 cm depth); accumulations of litter and humus at the base of trees and between buttress roots; the inside of dead tree stumps, logs, branches and twigs; the soil within and beneath very rotten logs; all mounds and subterranean nests encountered (checking for inquiline species); arboreal nests, carton runways, and sheeting on vegetation up to a height of 2 m above ground level. Termites specimens (Figure 1) collected for identification were stored in 80% isopropyl alcohol. The collected animals were identified by the authors with the key developed by them from earlier compilations (Bose, 1984; Chottani, 1997; Abe et al., 2000). After identification, the species were assigned to feeding groups as per classification of Donovan et al. (2001).

RESULTS AND DISCUSSION

A total of thirteen species was identified by the survey. They belong to six genera of family, Termitidae and one genus of the family Rhinotermitidae.

In turn, Termitidae is represented by three sub-families. Of these, *Hypotermes obscuriceps* Wasmann, *Macrotermes convulsionarius* Konig, *Odontotermes anamallensis* Holmgren and Holmgren, *Odontotermes brunneus* Hagen, *Odontotermes globicola* Wasmann, *Odontotermes* spp., *Microtermes incertoides* Holmgren and *Eremotermes paradoxalis* Holmgren belong to the sub-family Macrotermitinae. *Microcerotermes cameroni* Synder and *Microcerotermes. pakistanicus* Akhtar are of the sub-family Amitermitinae, while Nasutitermitinae is represented by *Trinervitermes sensarmai* Bose, *Trinervitermes biformis* Wasmann. The Rhinotermitidae is represented by *Coptotermes heimi* Wasmann, belonging to the sub-familiy Coptotermitinae (Table 1). The proportion of the identified species based on the number of individuals sampled is shown in Figure 2. *H. obscuriceps* was the most abundant (52%) followed by *M. convulsionarius* (23%).

Odontotermes annamallensis *Microcerotermes cameroni*

Odontotermes brunneus *Hypotermes obscuriceps*

Figure 1. Termite species sampled during the survey.

Feeding and nesting habits

Table 1 presents the species identified in the present survey and the six types of classifications to which they belong. Of these, the classification of Abe (1987) is based on nest type and foraging habit. It distinguishes between single-piece, intermediate and separate-piece nesters. Single-piece nesters feed and nest in the same discrete substrate; wood-feeding termites are in this category. Intermediate nesters nest in their feeding substrate but also forage out from the colony centre to find other patches of feeding substrate nearby. Again, these are all wood-feeding termites. Separate-piece nesters do not nest in their feeding substrate and actively forage for their feeding substrate away from the nest, which does not act as a primary feeding substrate.

The other classifications on which these authors' assessment has been done (Table 1) include the scheme of Donovan et al. (2001a), based on gut content analysis correlated with the morphology and anatomy of worker termites. This classification has been followed widely (Jones and Prasetyo, 2002; Davies et al. 2003; Bignell, 2011). The classification of Eggleton and Tayasu (2001) which is also called lifeway classification, combines the features of Abe's lifetypes and Donovan's feeding groups. It comprises eight groups– six categories of non-single piece nesters, and one each of dry wood and wet wood nesters. The eight groups are distributed across the gradients of humification and the degree to which the feeding and nesting substrates overlap. In the scheme of Yamada et al. (2007), termites are slotted into two major feeding groups - wood/litter feeders (including fungus-growers) and soil feeders. Lastly DeSouza and Cancello (2010) classified termites into four feeding groups or functional taxonomic groups, according to the proportion of the humification gradient they feed on. The substrates from where the termites were collected indicate their feeding preference. Based on this, the species were matched with the six classifications summarized (Table 1). *C. heimi* is a single piece nester, feeding on

Table 1. Taxa and the feeding groups of the termites recorded from the Pondicherry University campus.

Name of the species	Foraging/feeding substrate	Life type classification of Abe (1987) based on nesting type and foraging habit	Feeding group of Donovan et al., (2001)	Lifeway classification of Eggleton and Tayasu (2001)	Feeding group Yamada (2007)	Feeding group of DeSouza and Cancello (2010)
Hypotermes obscuriceps Wasmann	Mound and leaf litter	Separate-piece nesters	II	Sep(II)	Wood/litter feeders	II
Macrotermes convulsionarius Konig	Leaf litter	Separate-piece nesters	II	Sep(II)	Wood/litter feeders	II
Odontotermes anamallensis Holmgren and Holmgren	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes brunneus Hagen	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes globicola Wasmann	Dead wood and leaf litter	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Odontotermes spp.	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Microtermes incertoides Holmgren	Grass and cardboard	Separate-piece nesters	II	(III)	Wood/litter feeders	II
Eremotermes paradoxalis Holmgren	Leaf litter and soil	Separate-piece nesters	IV	(IV)	Soil feeders	IV
Microcerootermes cameroni Synder	Grass	Separate-piece nesters	II	(III)	Wood/litter feeders	II
Microcerootermes pakistanicus Akhtar	Dead wood	Separate-piece nesters	II	(III)	Wood/litter feeders	II
Trinervitermes sensarmai Bose	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Trinervitermes biformis Wasmann	Dead wood	Intermediate nesters	II	Int(II)	Wood/litter feeders	II
Coptotermes heimi Wasmann	Dead wood	Single-piece nesters	I	Sing(I)ww	Wood/litter feeders	I

Feeding groups of Donovan et al. (2001): I= dead wood and grass-feeders, II= Termites with a range of feeding habits including dead wood, grass, leaf litter, and micro-epiphytes, III= feeding in the organic rich upper layers of the soil, IV= true soil-feeders, ingesting apparently mineral soil).(Feeding group of DeSouza and Cancello (2010): I=Wood and grass feeders, II= Litter feeders, III= Soil feeders, IV= Soil feeders) (Lifeway classification of Eggleton and Tayasu (2001): Sing(I)ww= Group I [wood (wet and dry), grass, detritus], lifetype single; Int(II)=Group II (wood, fungus, grass, detritus, litter, microepiphytes), lifetype intermediate; Sep(II)=Group II (wood, fungus, grass, detritus, litter, microepiphytes), lifetype separate; Group III= soil–wood interface, soil feeder;Group IV=soil feeder.Group III and IV are not classified by life types.

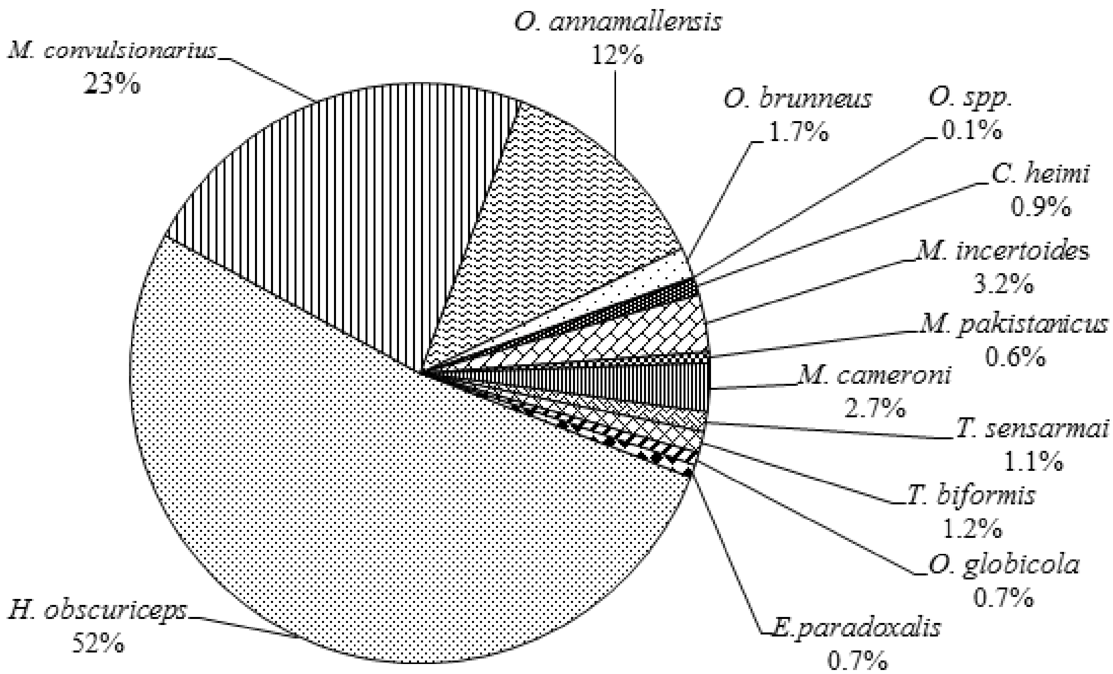

Figure 2. Proportion (number of individuals expressed in %) of the identified termite species.

dead wood. *E. paradoxalis* is the only true soil feeder with separate piece nest type. The other eleven species are wood/litter feeders having a wide range of feeding habits including dead wood, grass, leaf litter, micro-epiphytes, fungus-comb, and conidia. They are either separate piece nesters or intermediate nesters. Hence, it can be deduced that except *E. paradoxalis*, all the other species found in the present survey are suitable for use in termigradation as they all have orgainc material as part of their diet.

Present work in the context of past surveys

Most surveys of termifauna done so far have largely been of an ad-hoc nature and have not been based on any structured methodology amenable to statistical analysis such as line transect, belt transect, quadrat or other systematized survey method (Abbasi et al., 2015). Pardeshi et al. (2010) and Kumar and Pardeshi (2011), in separate surveys conducted in Vadodra, recorded fifteen termite species in agricultural fields. As the focus of these studies was to assess the damage to the agricultural crops, the samples of termites were taken only from the individual plants. In similar studies, Kumar and Thakur (2010, 2013) recorded fifteen species and twenty seven species, respectively, in the states of Haryana and Punjab.

Attempt was made to compare the species richness and diversity of termites sampled in the present study with that of others who have also followed similar methods of sampling and indices development. Hemachandra et al. (2010) examined termite assemblages in patches of undisturbed natural forest and secondary forest spanning 432 ha. In addition, random collections of termites were carried out in both the forests for species determination. They recorded eleven species overall: nine species in the secondary forest (four species by transect sampling, three by random sampling and two by both methods), and two species in the natural forest of which neither was recorded from secondary forest. As a consequence, the Shannon diversity index as computed by them was higher for the secondary forest (1.63) as compared to the natural forest (0.68).

In the present study, thirteen species were found; one soil feeder and the rest wood/litter feeders. The Shannon index of the study area is much higher (H'=1.45) as compared to the natural forest surveyed by Hemachandra et al. (2010). They recorded only soil feeders from natural forest, and attributed the absence of wood feeders there to the natural forest's altitude and climate. Moreover, they reported only five dominant species of trees and the litter comprised of small twigs of pencil size and sparse leaf litter in the natural forest. The present study area has much more diverse tree species and the litter generated is of different types ranging from small to large leaves, small twigs to large barks, shallow patches of litter to thick mulch covering large spans. Hence, there is more number of litter/wood feeding termites in the study area than in the Hantane forest reported by Hemachandra et al. (2010).

Carrijo et al. (2009), who followed the same methodology as in the present study except that their transects were twice as long, surveyed two areas: pasture and natural vegetation of State Park, Goias, Brazil. They recorded a total of twenty nine species (seventeen in pasture and twenty one in natural vegetation). The Shannon diversity indices were 2.55 and 2.82 for pasture and natural vegetation, respectively. Brazilian savanna is the richest tropical savanna in the world (DESilva and Bates, 2002) and part of the world's 25 biodiversity hotspots. Hence, as expected, the Shannon diversity index in both vegetations (2.55 and 2.82 at pasture and natural vegetation, respectively) are higher than that of the present study area (1.45).

Zeidler et al. (2002) surveyed for termites in five farms in the Southern Kuene region, Namibia. In each farm, they studied a site each of high and low land use intensity. In each area, 400 m^2 was surveyed which is twice the area normally used for representative sampling (Jones and Eggleton, 2000). They reported a total of ten species and concluded that termite species assemblages differed between the various forms, as well as across the land-use intensity gradients. The Shannon indices obtained by them ranged from 0–1.46, indicating zero diversity to moderate diversity. Dosso et al. (2010) while studying four different habitats differing in their vegetation and fire history: annually burned savanna, savanna woodland, forest island and gallery forest, in Cote d'Ivoire, West Africa, recorded a total of thirty species. The Simpson index for the areas ranged from 0.80 to 0.90 which indicates generally a low diversity as compared to the present study in which the Simpson index value of 0.34 represents high diversity (Table 2).

Among the four habitats studied by them, the forest island was the richest, followed by the gallery forest and savanna woodland. The forest island and gallery forest has more number of species as they act as refuge to species that are sensitive to regular fire that occurs in annually burned savannah. Between savanna woodland and annually burned savanna, savanna woodland had more number of species as the woodland consisted of savanna patches randomly unburned for five years, whereas annually burned savannah being fuel rich is burned deliberately every year.

The Pileou's indices reported by Dosso et al. (2010) ranged between 0.27–0.46 representing low to moderate evenness in distribution of species in four different study sites, whereas in the present study, the Pileous index of 0.57 indicate moderate evenness in that respect. Pielou's evenness values reported by Carrijo et al. (2009) are 0.94, 0.93 for pasture and for natural vegetation, respectively. The higher value indicates less variation among the species distributed in the natural vegetation as compared to the study area (0.57).

In another study conducted by the authors (Anantharaju et al., 2014) in Pondicherry Engineering College spanning about 210 acres, adjacent to the present study area, Pondicherry University, Puducherry, ten species were identified. In Pondicherry Engineering College, three species (*Microtermes obesi*, *Microcerotermes fletcheri* and *Neotermes assumuthi*) were identified which were not sampled from the present study area. Six species (*Microtermes incertoides, Eremotermes paradoxalis, Microcerotermes cameroni, Microcerotermes pakistanicus, Odontotermes* spp., and *Trinervitermes sensarmai*) were only found in the Pondicherry University campus and were not sampled from the Pondicherry Engineering College. The Simpson index of the Pondicherry Engineering College is 0.20 and the Shannon index is 1.83. The Pileous index of 0.75 shows less even distribution of the species in Pondicherry Engineering College as compared to the present study (0.57).

Hence it can be concluded that termite species in the present study area exhibit moderate evenness in distribution. The Simpson's index of 0.34 indicates more number of rare species (*M. pakistanicus, O. globicola, E. paradoxalis*) than abundant species. On the other hand, the high (1.45) Shannon diversity index indicates that there are a few abundant species as well (*H. obscuriceps, M. convulsionarius*). The authors have also conducted survey of termites by bait method in the study area to check if any species is missed in the survey reported in this study (Kaur et al., 2013). The baits attracted six species which were otherwise also sampled using transect and quadrats.

Conclusion

A repertoire of locally established termite species was developed using a systematic survey. A total of thirteen species belonging to two families: Termitidae and Rhinotermitidae; four subfamilies: Macrotermitinae, Amitermitinae, Nasutitermitinae and Coptotermitinae and eight different genus were identified. Out of the thirteen identified species, twelve belonged to higher termites and one to lower termites. *H. obscuriceps* was the most abundant and dominant species. The rare species were *M. pakistanicus, O. globicola* and *E. paradoxalis*. Anantharaju et al. (2014) reported ten termite species from the Pondicherry Engineering College (PEC). In the present study, six termite species were found in the University campus that were not seen at PEC (*C. heimi, M. incertoides, M. pakistanicus, M.cameroni, T sensarmai* and *E. paradoxalis*).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Table 2. Comparison of the diversity and evenness indices of the present study with other studies.

Range and inference	The present study	Hemachandra et al. (2010)	Dosso et al. (2010)	Carrijo et al. (2009)	Zeidler et al. (2002)
Study area	A thickly wooded campus (of Pondicherry University) at the East Coast of the Indian Peninsula	Two forest area : natural and secondary forest, Hantane forest range in Sri Lanka	Savanna, Cote d'Ivoire, Africa	Savanna, Brazil	Five farms in Northwestern Namibia
Number of species recorded	Thirteen	Eleven	Thirty one	Twenty nine	Six
Span of area covered (ha)	780	432	Not reported	2,862.3	Not reported
Simpson's index Range: 0-1 0: Infinite diversity 1: No diversity	0.34 (High diversity)	-	0.80-0.90 (low diversity)	-	-
Shannon index Range: 0-4 Higher value represents greater diversity	1.45 (moderate diversity)	1.63 (secondary forest : moderate diversity) 0.68 (natural forest : lower diversity)	-	2.55 (pasture) (high diversity) and 2.82 (natural vegetation) (high diversity)	0 to 1.46 (no diversity to moderate diversity)
Pielou's index Range: 0-1 Higher the value more even the distribution	0.57 (moderate eveness in distribution)	-	0.27 to 0.46 (low to moderate distribution)	0.93 to 0.94 (even distribution)	-

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Assessing crop and livestock losses along the Rungwa-Katavi Wildlife Corridor, South-Western Tanzania

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Humans and wildlife interact negatively, especially when humans transform natural wildlife habitats by establishing settlements and crop fields. Encroachment and habitat fragmentations caused by human activities decrease habitat size and quality for wildlife and reduce connectivity among protected areas. The major objective was to quantify economic loss inflicted by wildlife species to local communities in terms of crop and livestock losses. The influence of distance from the boundary of the protected area was also assessed. 240 copies of open and closed ended questionnaire were randomly administered in five selected villages in the Rungwa-Katavi Corridor between the Rungwa Game Reserve and Katavi National Park. The average loss to wildlife per household was 430 kg of crops, equivalent to US $126.23, as well as livestock, including cattle (0.9), goats (0.6), sheep (0.3), and donkeys (0.09) equivalent to US $260.23 per household per year. The reported incidences of crop damage and livestock attack varied among different age groups and between genders. The depredation and crop raiding incidences increased with proximity to the protected areas as contact with predators and vermin animals was higher closer to the protected areas. Implementing proper land use planning for livestock keepers, crop production and conservation land is recommended as an effective strategy to safeguard protected areas and minimize human-wildlife conflict.

Key words: Human-wildlife conflict, crop damage, livestock depredation, Rungwa Game Reserve, wildlife corridor.

INTRODUCTION

Transformation of wildlife habitats into croplands, settlements and grazing lands for livestock increasingly threatens the future survival of wild animals in areas surrounding protected areas in Tanzania and the rest of

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the world; protected areas are becoming islands (Akenden, 2015; Woodroffe, 2000). According to the United Nations list of world protected areas, protected areas covered a total area of 32,868,673 km^2 worldwide in 2014, which accounts for 14% of the terrestrial world land area and 3.4% of the marine protected area network (Deguignet et al., 2014). Approximately, 65% of the global protected area network sites are in Europe. However, they account for only 12% of the total area covered by protected areas worldwide. Africa has fewer sites of protected areas, but these sites account for 13.8% of the total area covered by the global protected area's network (Juffe-Bignoli et al., 2015). The largest terrestrial protected area in the world is found in Greenland. The Republic of Tanzania is well known for setting aside approximately 45% of its land as protected areas under different categories such as National Parks, Game Reserves, Forest Reserves, Wildlife Management Areas, and Game Controlled Areas (IUCN, 2017; TNRF, 2008).

The fragmentation and loss of habitat facing many protected areas is exacerbated by the rapidly growing human population. Tanzania's human population has increased from approximately 7 million in 1961 to approximately 45 million in 2012 (URT, 2013). With an annual growth rate of 3.1%, Tanzania's population is projected to reach 69.1 and 129.1 million in 2025 and 2050, respectively (PRB, 2013). More than 80% of the country's population depend on small scale agriculture and livestock as their major livelihood strategies. According to the population census of 2012, more than 75% of the Tanzanian human population are young, below the age of 35 years; most are unemployed and reside in areas that are also wildlife habitats or corridors, thus blocking wildlife movements from one protected area to another (Caro et al., 2009; Hariohay and Røskaft, 2015).

Humans and wildlife interact adversely when wildlife disperses from core protected areas (PAs) through the premises of local communities. In such cases they destroy crops, depredate on livestock and pose a threat to human security. Such interactions cause negative attitudes towards wild animals and their conservation (Nyahongo, 2007). Other negative impacts are the increase in time spent in guarding farms and livestock and other infrastructures such as water sources (Shemweta and Kideghesho, 2000).

Areas currently used by humans were historically used by wild animals as habitats, especially when they are moved from one protected area to another (Caroet al., 2009). The negative human-wildlife interactions were minimal because the human population was low; consequently, demand for settlements, agricultural and grazing lands was low. Over the last several decades, human population growth has led to increased encroachment on dispersal areas and wildlife corridors, causing small, non-continuous patches of habitats. Opening of new agricultural fields and nomadic pastor.

Nomadic pastoralism are traditional farming methods used by local communities in the villages surrounding most protected areas in Tanzania and are detrimental to future existence of these protected areas (Kideghesho, 2015). The impact of human beings on wildlife is not well understood, but the disturbance to wild animals creates stress, which might affect their ability to reproduce (Tingvold et al., 2013).

Among the dominant livestock owners in Tanzania are the people of the Sukuma tribe. Increasing conversion of land to settlements and croplands and impacts of climate change have forced movement of these people further South to Rungwa-Katavi from Shinyanga, Tabora, Simiyu, and Mwanza regions (Figure 1). This movement has subjected the area to rapid human population increase and therefore anthropogenic activities such as land clearing to open up fields, charcoal burning, timber, settlements and overgrazing leading to habitat deterioration (Caro et al., 2009; Hassan, 2003; Kideghesho et al., 2006). These activities have adversely affected the Rungwa-Katavi Wildlife Corridor, which is ecologically important for large mammals including African elephants (*Loxodonta africana*), African wild dogs (*Lycaon pictus*), hartebeests (*Alcelaphus buselaphus)*, impala (*Aepyceros melampus),* greater kudus (*Tragelaphus strepsiceros*) and lesser kudu (*Tragelaphus imberbis*). As in other areas of Tanzania, the pressure to degazette the protected areas to allow other human uses has increased in Rungwa-Katavi in recent years. However, the question is: what will occur if such areas do not exist? Some have argued that this would provide suitable grazing land for livestock keepers. Establishing and implementing proper land use and management strategies at the village level will avoid unnecessary conflicts between livestock owners and protected area management and enhance sustainable conservation of wildlife resources.

Objectives

The main aim of this study was to assess the economic loss inflicted by wildlife species to local communities living in the Rungwa-Katavi wildlife corridor, connecting the Rungwa Game Reserve and the Katavi National Park.

The specific objectives were: (1) to identify the cost of livestock and crop damage by wildlife in the study area; (2) to assess the relationship between crop and livestock damage to distance from protected area.

Two hypotheses were tested: first, there is no significant loss caused by wildlife to crop and livestock in the study area and secondly, there is no significant difference between livestock depredations and crop damage with the distance to the protected area.

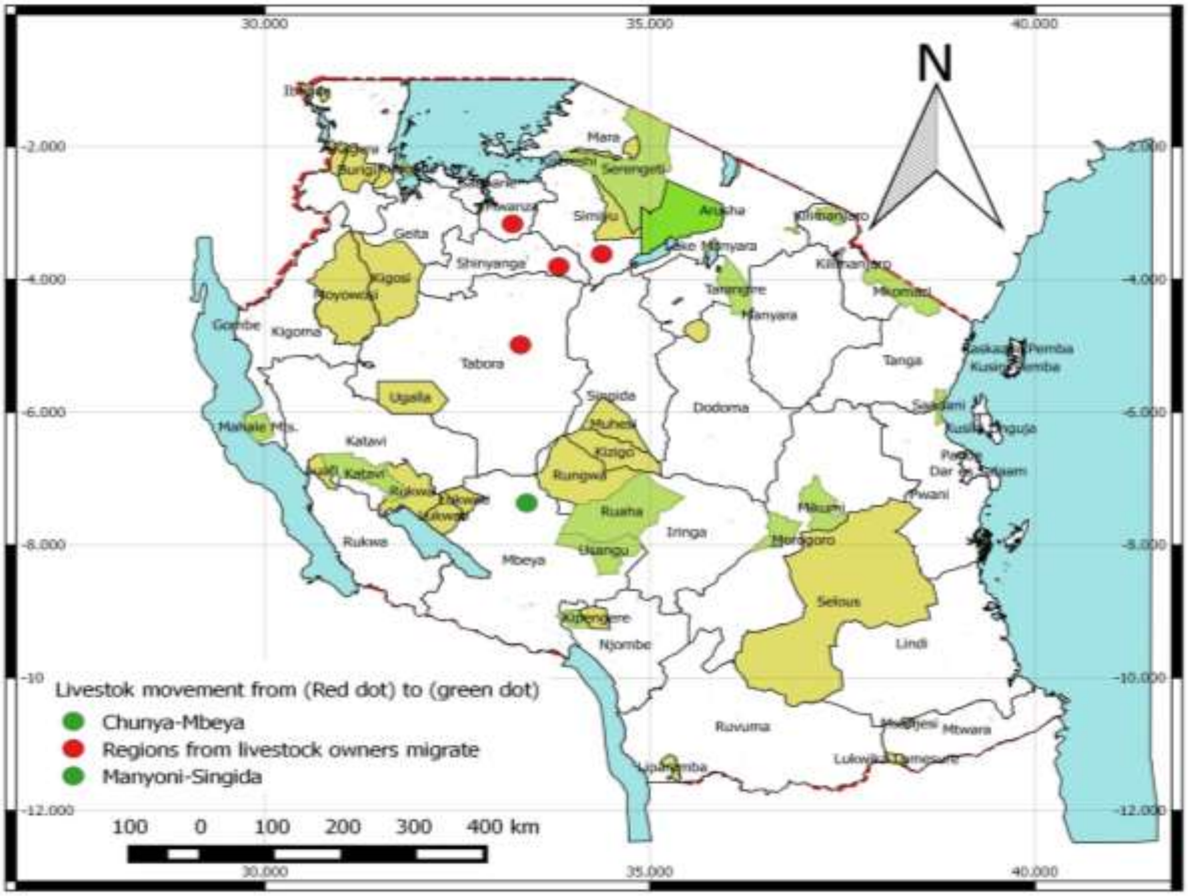

Figure 1. The regions where livestock keepers migrate from (red dots) and the regions they go to (green dot).

MATERIALS AND METHODS

Study area

The Rungwa-Katavi Wildlife Corridor connects the Rungwa/Kizigo/ Muhesi Game Reserves in the east and on the western side of Katavi National Park with the Lukwati/Piti and Rukwa/Lwafi Game Reserves (Figure 1). The Rungwa-Ruaha Ecosystem is the second stronghold, after the Selous-Mikumi Ecosystem, for a large population of African elephants (TAWIRI, 2014). The corridor covers an area of 9,378.58 km^2 located in the east between S 6.97421, E 33.51251 and S 7.80476, E 33.83169 and in the west between S 7.71328, E 33.50591 and S 7.16871, E 32.70056. The corridor comprises the area between the Matandala and Mbanga Mountains, which is a water catchment that supplies the Lukwati Game Reserve and the Mwipa and Mwise Rivers feeding into the Rungwa River. From the west, elephants move from the top of the Lake Rukwa Escarpment, along the Lukwati River, and then on to the Mwipa and Mwise Rivers and northwards to the Piti and Rungwa Rivers during the dry season. Similarly, elephant movements occur from Ruaha National Park and Rungwa Game Reserve to the east towards the Mwaliji/Lueja Rivers during the dry season (Jones et al., 2012).

People residing in this area are agro-pastoralist reliant on farming and beekeeping as their major social economic activities. Tobacco, sesame and sunflower are cultivated as cash crops, whereas maize, beans and millet are major food crops. Most of the immigrants practice both crop cultivation and livestock keeping, while the residents mostly depend on crop cultivation and few depend on beekeeping and selling bee honey as source of household income. The main ethnic groups include Kimbu, Nyamwezi, Sukuma, Fipa, Nyakyusa, Safwa, Gogo, Sangu, Nyaturu, and Taturu. The others, such as Kurya and Haya, are in minority.

Experimental

'A total of 240 respondents was randomly selected and interviewed from five villages. Villages were grouped into two categories: (1), those in proximity to the boundary of the Game Reserve (Kanoge and Kambikatoto) and (2) the villages further away from the Game Reserve (Isangawana, Kipembawe and Mafyeko) (Figure 2). In each village, 48 copies of the questionnaire were randomly administered to respondents, aged 18 years and above. The researcher worked from the village centres, where he randomly stopped people for interview. The researcher then moved to the next centre with a high concentration of people. Several questions were asked aimed at gathering information about their interactions with wildlife, as well as the demography and socio-economic activities of the respondents. The other part of the questionnaire contained questions on crop damage incidences, types of wildlife

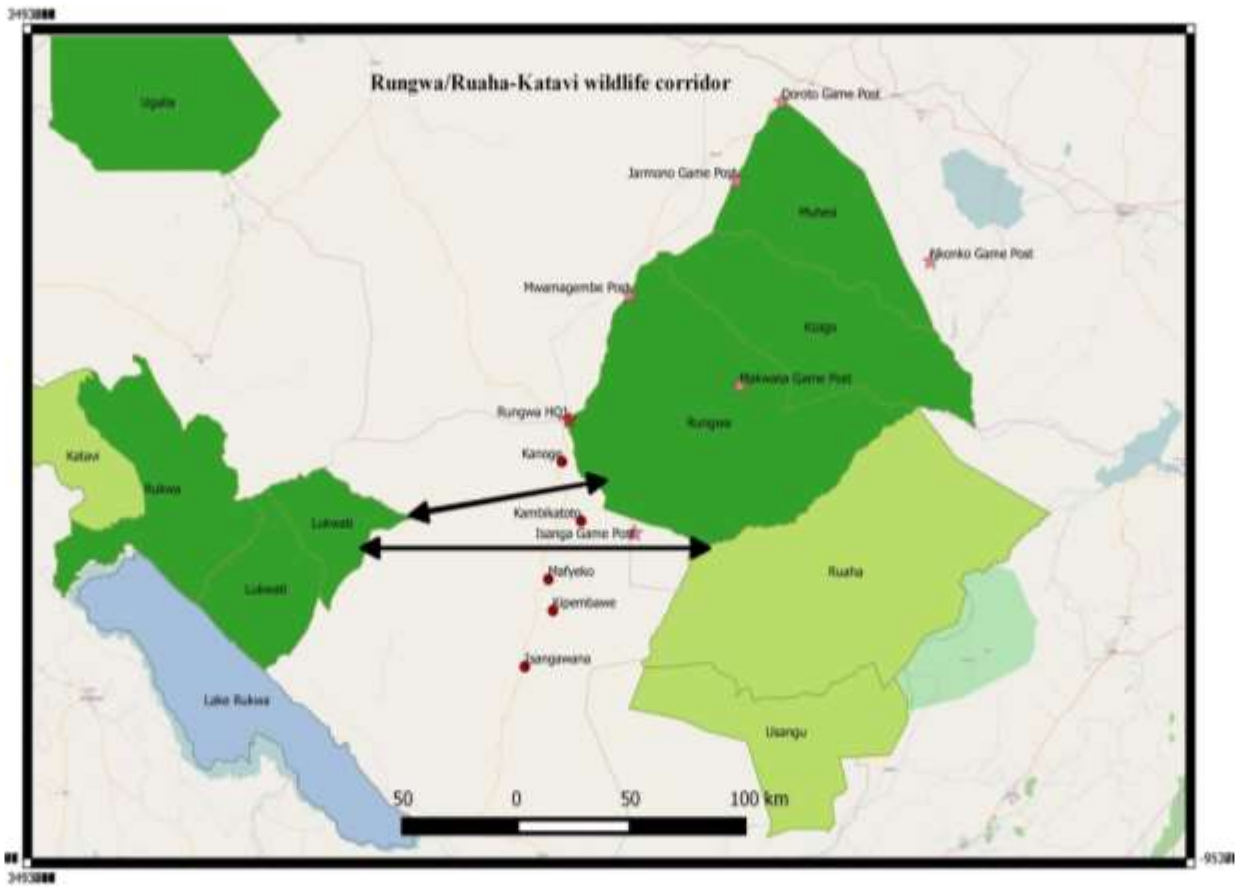

Figure 2. Rungwa– Katavi wildlife corridors represented by arrows and study villages by red dots.

responsible, livestock depredations incidences, type of predators responsible and mitigation measures used.

Statistical analyses

Quantitative data were processed and analysed using Statistical Package of Social Science (SPSS) version 19.0. Descriptive statistics were used to generate means and percentages, which are important for comparison purposes. Chi-square tests were used to determine the significant differences among the research results. Non-parametric statistics were mostly used when data were not normally distributed. The significance level was set at $p < 0.05$. Finally, linear regression or logistic regression analyses was used to test the most influential factors.

RESULTS

Social-demographic variables of the respondents

The 240 respondents included both males (68.8%) and females (31.2%). The majority of respondents were in the 37 to 55 years age group (48.3%), followed by 18 to 36 years (32.5%) and above 55 years (19.2%). 61.2% of the respondents had attended primary school, while less than 1.3% had been to secondary school and 37.5% were illiterate. Two-thirds (66.7%) of the respondents were indigenous and 33.3% were immigrants. The main socioeconomic sources of income were crop cultivation (64.6%), followed by livestock keeping (31.2%) and employment/business (4.2%). A majority of the respondents (60%) came from distant villages, and only 40% lived close to the protected area. 12.9% of respondents had no dependants, while 6.7% had >10 dependants, 27.5% had 5 to 10 dependants, and 52.9% had <5 dependants.

Livestock ownership

Out of 240 respondents, only 32.1% owned livestock. Most of the livestock owners owned 62 cattle (80.5%), while a minority owned 8 goats (10.4%), 4 sheep (5.2%) and 3 donkeys (3.9%). There was a significant increase in livestock ownership with age, as the majority of livestock owners were in the >55 years age category, followed by those in the 37 to 55 age category, with the

Table 1. Livestock ownership versus age, gender, tribe (Sukuma vs. others combined), marital status, dependants and education in the Rungwa-Katavi Wildlife corridor (N = 240).

Variable	Description	Livestock ownership			χ^2	df	P
		Yes (%)	No (%)	Number			
Age (years)	18-36	19.2	80.8	78	41.78	2	<0.0001
	35-55	25.0	75.0	116			
	>55	71.7	28.3	46			
Gender	Male	38.2	61.8	165	9.02	1	<0.003
	Female	18.7	81.3	75			
Tribe	Indigenous	2.5	97.5	160	192.8	1	<0.0001
	Immigrants	91.2	8.8	80			
Marital status	Married	37.9	62.1	195	17.72	3	<0.001
	Not married	0.0	100.0	23			
	Divorced	20.0	80.0	10			
	Widowed	8.3	91.7	12			
Numbers of dependants	0	0.0	100.0	31	68.94	3	<0.0001
	<5	19.7	80.3	127			
	5-10	56.1	43.9	66			
	>10	93.8	6.2	16			
Education level	Not been to school	81.1	18.9	90	158.9	1	<0.0001
	Been to school	2.7	97.3	150			

least livestock owners in the 18 to 36 age category (Table 1). Most of the livestock owners were immigrants; very few were from the indigenous group (Table 1).

The majority of the respondents who had not been to school owned livestock, while very few of who had been to school owned livestock, with a statistically significant difference (Table 1). There was a significant difference between married and unmarried respondents in terms of livestock ownership, as most of those who owned livestock were married and only a few who were not married owned livestock (Table 1).

Livestock ownership significantly varied with the number of dependants, as those respondents with no dependants did not own livestock. Livestock ownership increased with the number of dependants respondents had: respondents with <5 dependants owned few livestock, followed by respondents with 5 to 10 dependants; more than 90% of respondents with >10 dependants owned a large quantity of livestock (Table 1).

Livestock depredation

More than half of the livestock owners (54.5%, N = 77) had experienced livestock depredations. Depredation incidences varied with distance from the PA, as most respondents close to the PA (81.5%) experienced depredation, while 40.0%, of the respondents from distant villages reported fewer depredation cases; this difference was statistically significant (Table 2). Livestock depredation varied significantly between male and female respondents, as more males reported more depredation incidences than females (Table 2). Depredations reports varied with tribe, as the Sukuma tribe reported a higher livestock depredation incidence than all of the other tribes combined (Table 2).

Additionally, depredation incidences varied with education level, as more of those who had not attended formal education reported depredation incidences than those who had attained formal education (Table 2). However, depredation incidences did not differ between any of the groups, including age and marital status (Table 2).

Livestock killed and economic loss

Respondents estimated the average loss of killed

Table 2. Livestock depredation (among livestock owners) versus gender, age and distance to PA, residency, marital status and education level of respondents.

Variable	Description	Livestock depredation Yes (%)	Livestock depredation No (%)	Livestock depredation Number	χ^2	df	P
Gender	Male	67.3	32.7	55	4.54	1	0.03
	Female	40.9	59.1	22			
Age (years)	18-36	60.0	40.0	15	0.50	2	0.77
	37-55	58.6	41.4	29			
	>55	60.6	39.4	33			
Villages	Close	81.5	18.5	27	12.17	1	0.0001
	Far	40.0	60.0	50			
Tribe	Indigenous	0.0	100.0	4	5.06	1	0.02
	Immigrants	57.5	42.5	73			
Marital status	Married	60.8	39.2	74	3.25	2	0.196
	Not married	0.0	0.0	0			
	Divorced	0.0	100.0	2			
	Widowed	100.0	0.0	1			
Education	Not been to school	57.5	42.5	73	5.06	1	0.02
	Been to school	0.0	100	4			

Percentages are respondents who replied yes and no to livestock depredation in the Rungwa-Katavi wildlife corridor.

livestock per person per year to be 1.9 animals (N = 43). Cattle were most often reported as killed by depredation (55.8%). Other livestock killed included goat (25.6%), sheep (11.6%), and donkey (7%). In the local markets where this study was conducted, cattle are sold at an average price of US $250/animal: goats and sheep are sold at an average price of US $30/animal and donkeys were sold at an average price of US $60/animal.

A total of 83 livestock were recorded killed, which included 39 cattle, 26 goats, 14 sheep, and 4 donkeys, equivalent to an average of 0.9, 0.6, 0.3, and 0.09 animals killed, respectively, per year per household. In monetary terms, cattle contributed greatest the economic loss (US $226.74), followed by goats (US $18.14), sheep (US $9.77) and donkey (US $5.58) per year to the households that reported depredation incidences. The total economic loss caused by livestock depredation in this study is about US $11,190.00, which is an average of US $260.23 per year per household.

Type of predator

Spotted hyenas was the most common predator, reported to cause 53.5% (N = 23) of the depredation incidences, followed by lions (25.6%, N = 11) and leopards (20.9%, N = 9). The frequency of type of predator and livestock killed varied statistically significantly; lions attacked only cattle (100.0%, N = 16), while hyenas attacked mostly cattle (44.4%, N = 18), followed by goats (38.9%, N = 18) and donkeys (16.7%, N = 18); finally, leopards attacked goats (44.4%, N = 9) and sheep (55.6%, N = 9) (χ^2 = 40.68, df = 6, P < 0.0001).

A binary logistic regression using livestock loss (yes/no) as a dependent variable and the distance to PA, gender, marital status, age, residency (immigrant or not), education level, number of dependants, and number of livestock killed as independent factors. Distance from PA was the only statistically significant factor and explained the 53.1% variation in livestock depredation incidences (Table 3). The other independent variables did not explain any of the variation (Table 3).

Crop damage

The majority (92.5%) of the respondents owned a piece of land and were peasants (Table 4). The most common crop grown was maize (60.4%); the other types (39.6% combined) included sunflower, beans, sesame, groundnut and tobacco. Land ownership variation was statistically significant with age; respondents 18 to 36 years owned

Table 3. Binary regression analysis with depredation cases of livestock as the dependent variables versus independent variables (age, distance, dependants, sex, marital status, residency, education and socio-economic activities and livestock type).

Dependent variable	Independent variable: Livestock depredation		
	Wald	df	P
Distance	9.471	1	0.002
Gender	2.615	1	0.106
Dependants	2.702	1	0.100
Marital status	0.551	1	0.458
Immigration status	0.0001	1	0.999
Age	2.861	1	0.091
Education	0.000	1	0.999
Income	0.0001	1	0.999
Constant	0.0001	1	1.000

Percentage are respondents who replied yes and no to livestock depredation in the Rungwa-Katavi wildlife corridor.

Table 4. Land ownership versus age, gender, tribe (Sukuma vs. others combined), marital status, dependants and education in the Rungwa-Katavi Wildlife corridor (N = 240).

Variable	Description	Land ownership			χ^2	df	P
		Yes (%)	No (%)	Number			
Age (years)	18-36	76.9	23.1	78	40.41	2	≤0.0001
	35-55	100.0	0.0	116			
	>55	100.0	0.0	46			
Gender	Male	91.5	8.5	165	0.73	1	≤0.39
	Female	94.7	5.3	75			
Tribe	Indigenous	89.4	10.6	160	6.76	1	≤0.009
	Immigrants	98.8	1.2	80			
Marital status	Married	97.9	2.1	195	104.9	3	≤0.0001
	Not married	39.1	60.9	23			
	Divorced	100.0	0.0	10			
	Widowed	100.0	0.0	12			
Numbers of dependants	0	54.8	45.2	31	73.49	3	≤0.0001
	1-4	96.9	3.1	127			
	5-10	100.0	0.0	66			
	>10	100.0	0.0	16			
Education level	Not been to school	96.7	3.3	93	8.05	1	≤0.02
	Been to school	89.8	10.2	150			

less, while all respondents in the 37 to 55 age group and the above 55 years group owned land (Table 4).

Approximately 45.9% of the peasants experienced crop damage (Table 5). There was a significant difference between close and distant villages, as respondents close to the PA experienced more damage than those far away (Table 5). Reported crop damage incidences varied with the age of the respondents (Table 5). Respondents in the 37 to 55 years age category reported the most crop damage incidences, followed by the >55 years age group; the 18 to 36 years' age group reported less crop damage incidences (Table 5). The gender of respondents

Table 5. Crop damage (among farmers) versus gender, age and distance to PA, residency, marital status and education level of respondents.

Variable	Description	Crop damage			χ^2	df	P
		Yes (%)	No (%)	Number			
Gender	Male	60.9	39.1	151	6.80	1	≤0.009
	Female	42.3	57.7	71			
Age (years)	18-36 years	41.7	58.3	60	8.39	2	≤0.010
	37-55 years	63.8	36.2	116			
	>55 years	50.0	50.0	46			
Villages	Close	80.9	19.1	89	40.3	1	≤0.0001
	Far	37.6	62.4	133			
Tribe	Indigenous	52.4	47.6	143	1.02	1	≤0.312
	Immigrants	59.5	40.5	79			
Marital status	Married	56.0	44.0	191	2.00	3	≤0.570
	Not married	33.3	66.7	9			
	Divorced	60.0	40.0	10			
	Widowed	50.0	50.0	12			
Education	Not been to school	58.0	42	88	0.53	1	≤0.467
	Been to school	53.0	47	134			

Percentage are respondents who replied yes and no to crop damage in the Rungwa-Katavi wildlife corridor.

varied significantly in terms of reporting crop damage; more males reported crop damage incidences than female respondents (Table 5). Reported crop damage incidences did not differ significantly between any of the other groups, including education, tribe and marital status (Table 5).

Crop damaged and economic loss

The most commonly damaged crop was maize (97%). The average loss included 417 kg of maize, which is equivalent to US $125 per year per household. Other crops accounted for an average loss of 13 kg per year per household, which is equivalent to a loss of US $1.30 per year per household. Respondents ranked the problem animals causing crop damage. Elephant was the most problematic animal (96.1%) followed by warthog (2.9%) and greater kudu (1%).

Measures to control problem animals

More than three-quarters of the respondents (76.7%) reported controlling problem animals by guarding (25.8%) and scaring by lighting fires and making noises (57.5%). Other strategies cited by 16.7% of the respondents included farming away from the borders of the PAs, growing crops such as pepper that are undesirable to wild animals, or smearing dirty oil on raised poles along the borders of the field.

A binary logistic regression analysis was performed with crop damage incidences as the dependent variable and with the same independent variables as for livestock depredation. The 33.1% variation in crop damage was best explained by distance from the PA and gender (Table 6). Other variables including education, tribe, age, marital status, and crop type were not important variables in explaining the variation in crop damage (Table 6).

DISCUSSION

Connectivity between Wildlife Protected Areas has been an important topic for discussion for many scholars to maintain genetic flow and biodiversity stability (Weldon, 2006). Considering that many protected areas cannot accommodate populations of mega wildlife such as the African elephant and African wild dogs with large home ranges, wildlife corridors are important for facilitating species movement from one protected area to another. Today, many human-wildlife conflicts are caused by

Table 6. Binary regression analysis with crop damage as the dependent variables versus independent variables (age, distance, dependants, sex, marital status, residency, education and socio-economic activities and livestock type).

Dependent variable	Independent variable (Crop damage)		
	Wald	df	P
Distance	36.010	1	≤0.0001
Gender	11.170	1	≤0.001
Dependants	1.929	1	≤0.165
Marital status	1.227	1	≤0.268
Immigration status	0.235	1	≤0.628
Age	0.131	1	≤0.717
Education	0.024	1	≤0.877
Income	0.006	1	≤0.941
Constant	4.180	1	≤0.041

people who are encroaching on these corridors, which had previously been used by wild animals as habitats or stepping stones. Blockage of corridors and dispersal areas for wild animals caused by a rapid human population increase has resulted in the transformation of more wildlife habitats to croplands (Kideghesho et al., 2013, Watkins et al., 2003).

In this study, most of the respondents were males, which are attributed to the fact that males were more free and ready to talk to the researcher than females. All age groups were well represented. However, over 48% were between 37 and 55 years old. This age group owned livestock and agricultural land. Most of the respondents were growing crops for food and keeping livestock as their major source of income. Other sources of income included beekeeping and formal employment in tourist companies operating in the nearby protected areas. Kideghesho (2015) and Kideghesho et al. (2013) reported that dependency on small-scale farming and livestock keeping as major sources of income is common among the villages in areas bordering the protected areas in Tanzania. Researchers were interested mostly in the farmers and livestock keepers, as these groups are the ones incurring the costs of wildlife conservation from livestock depredation and crop damage.

Livestock depredation

Most livestock owners had experienced losses by various predators such as lions, hyenas and leopards as predicted in the first hypothesis. The edge effect theory can best explain why most of the large predators such as lions and hyenas require large home ranges; therefore, encroachment into wildlife habitats created small patches of habitats that increased the chances of predators attacking livestock (Nyahongo, 2007). More than 50% of the respondents mentioned spotted hyena as the leading predator, followed by lions and leopards. This might be explained by the fact that the Ruaha-Rungwa ecosystem has large populations of large carnivores and by the occurrence of encroachment of the livestock keepers and settlements near the borders of these protected areas. For example, a study by Kideghesho (2010) in the western Serengeti corridor indicated that spotted hyena was the most problematic predator, responsible for approximately 98% losses of livestock near the national park boundary. Additionally, spotted hyena can walk long distances, up to 20 km, in a single night and hide in small patches of forest in the village around the human settlement. Similar to our findings, Mwakatobe et al. (2013), reported the spotted hyena as the major livestock-killing predator in the western Serengeti ecosystem.

Reported depredation incidences varied with the distance from the protected area, with more reports from respondents living close to the PA, thus supporting our first hypothesis that impact varies with distance. The findings around Tarangire National Park by Hariohay and Røskaft (2015) and in the Serengeti by Mwakatobe et al. (2013) support our results, as they reported more livestock depredations near the PA than in distant villages. These results therefore support our first hypothesis. Mostly males complained about livestock depredation, which is attributed to the fact that men are responsible for herding cattle in African pastoralist societies such as the Sukuma. Therefore, they experienced more incidences of livestock attacks than females, corroborating the results of Treves and Karanth (2003).

According to respondents, the amount of losses incurred in terms of the number of livestock lost and the price in the local market was economically significant; this supported our second hypothesis: we expected crop and livestock losses in the study area. Economic loss of livestock was estimated to be US $260.23 per year per household in the five villages in and around the corridor.

The reported incidences of livestock depredation by hyenas and lions occurred mostly at night and are attributed to poorly built livestock “bomas” using tree poles. Most of the respondents justified their choice of not building strong and permanent buildings to keep their livestock in overnight by reasoning that they do not expect to live there for many years. The majority of the livestock owners in the area (Sukuma) had the habit of moving from one locality to another when the area becomes unsuitable for crop cultivation and the quality and quantity of pasture for their livestock decline. Generally, no proper protection measures have been taken by the livestock owners; most of the time, young boys (under 16 years old) had been looking after large herds of cattle during the day with temporary buildings for livestock during the night. Many of them depended on dogs; others employed a night watchman to guard their livestock premises, similar to what was reported by Lyamuya et al. (2016).

Crop damage

Most of the peasants in the area were victims of wild animals, as their crops had been destroyed by problem animals. More crop damage occurred in the villages close to PA. This is because villages close to the boundary of the wildlife protected areas face the most contact with wildlife such as elephants and other vermin species. Mwakatobe et al. (2014) had similar findings in the western Serengeti, as the crop damage happened at farms closest to the protected area. Most of the crop fields bordered the Rungwa Game Reserve. Crop damage took the form of trampling by elephants. Mfunda and Røskaft (2011) reported crop damage by problem animals in the western Serengeti and their findings support our results in that elephants caused more damage to crops such as maize, sunflower and groundnuts than other animals.

Respondents ranked elephants as the primary problem animal, causing over 90% of the crop damage. The damage occurs mostly during the night. Other animals such as the greater kudu caused crop damage at early stages of plant growth (tender) and destroyed crops mostly during the day; thus, the farmers could guard their crop fields, unlike during the night. An average of 430 kg of various crops was lost per household, which accounts for a significant amount of household income in the villages studied. The estimated amount was from the 222 households who had farmed in the study year. However, the most frequently lost crop type was maize, up to 417 kg; this was attributed to the fact that it was the most commonly cultivated crop. Research in the western Serengeti corridor by Kideghesho (2010) indicated crop losses to have accounted for about US $516 per household higher than our result of US $126.23 per household per year. The difference might be due to the difference in time when the two studies were conducted and fact that majority of communities living adjacent to the western Serengeti corridor are agro-pastoralist and wildlife migrate in that area. The crop losses caused by elephants and other wild animals are among the reasons for poverty among local people and exacerbate unsustainable wildlife conservation in the wildlife corridor. Kideghesho et al. (2007) and Adams et al. (2004) discussed the importance of biodiversity conservation benefiting local communities for the success of sustainable conservation of wildlife, and Bandara (2005) noted that habitat fragmentation is the primary source of conflict between elephants and human beings. Both our first and second hypotheses were supported: first that people faced negative impacts in terms of crop damage in the corridor and second that the crop damage incidences varied with the distance from the Rungwa Game Reserve.

CONCLUSION AND RECOMMENDATIONS

Crop raids and livestock depredation were directly influenced by the distance from the game reserve boundary. The findings supported our hypotheses: first, the negative interactions in terms of crop and livestock losses in the study area and second, that livestock depredation and crop damage occurred more often in villages close to the protected areas. Important factors that influenced crop damage incidences among respondents included age, gender and distance from the PA. Important factors that influenced reporting livestock depredations included gender, education, immigration status and distance from the protected area. It was found that among the immigrants, the Sukuma tribe (91.3%) reported the most livestock depredations.

It was found that livestock keepers lost an average of 1.9 animals to predators per household per year in the study area. The majority of livestock lost were cattle, followed by goat, sheep and donkey. The study recorded farmers to have incurred significant losses of crops, mainly maize (417 kg). Most livestock losses were incurred by the immigrants, but immigrants and residents incurred crop losses equally. This supported our first hypothesis that wildlife had caused significant livestock and crop losses in the study area.

It was recommended that the responsible wildlife authorities should provide education on control measures to prevent problem wild animals such as elephants from destroying their crop farms to reduce the economic losses incurred. Construction of strong bomas and herding practices are recommended to reduce the levels of livestock depredation. Also, it was recommend that communities around the Rungwa Game Reserve should avoid growing crops close to protected areas, as incidences of crop raiding by wild animals and livestock depredation increase towards the protected area boundary. The legislation should recognize wildlife corridors to increase their conservation status; Ministry of Natural Resources and Tourism (MNRT) should identify all remaining corridors that can be given conservation status and restrict anthropogenic activities that are ecologically destructive.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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